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Avionic Pictorial Tunnel-/Pathway-/Highway-In-The-Sky Workshops

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Proceedings of four interactive workshops sponsored by the National Aeronautics and Space Administration, Washington, D.C., and held at Langley Research Center, Hampton, Virginia
April 25-27,1994, September 20-22, 1994,
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Compiled by Russell V. Parrish

Foreword

Beginning in April, 1994, Langley Research Center held a series of interactive workshops that met off and on again at about six month intervals through September, 1996, to investigate tunnel-, pathway- or highway-in-the-sky concepts. These workshops brought together government and industry display designers, test pilots, and airline pilots to discuss and fly various pathway-in-the-sky concepts in an iterative manner.

The first two workshops were focused on the subject of advanced pictorial displays, regardless of the specific application. Rapid advances in computer graphics capabilities were enabling the consideration of possible new large-screen, integrated pictorial formats to provide gains in pilots' situational awareness, pilot/vehicle performance, and aircraft safety, with potential for significant operational benefits. The application of these "real-world", three-dimensional, pictorial displays in the form of "highway-in-the-sky" formats had been successful in providing complex-path guidance information to pilots in simulated commercial transport operations. These highway formats were being evaluated at various flight display research laboratories, including NASA Langley Research Center (LaRC). The most prominent feature of these advanced flight displays was the "pathway" element (a variation on the Naval Air Development Center "tile" pathway). This type of symbology had been shown, in both DoD and NASA research, to enable highly-precise flightpath control, especially for vehicles required to execute complex curved flightpaths, such as those that may be utilized for landing approaches to closely-spaced parallel runways.

The primary emphasis of these first two workshops was the utility and usability of pathways and the pros and cons of the various features available. While the specific application was unstated, the prevailing assumption was the pathway would be utilized within a Synthetic Vision-like system. Synthetic Vision Systems (SVS) are characterized by their ability to represent, in an intuitive manner, the visual information and cues that a flight crew would have in daylight -- Visual Meteorological Conditions (VMC). The view of the outside world is provided by melding computer generated airport scenes from on-board databases and flight display symbologies, with either information derived from a weather penetrating sensor (e.g., information from runway edge detection or object detection algorithms) or with actual imagery from such a sensor. The visual information and cues are depicted based on precise positioning information relative to the onboard terrain database, and includes traffic information from surveillance sources (such as TCAS, ASDE, etc.) and other hazard information (such as wind shear).

In contrast to synthetic vision systems, Enhanced Vision Systems (EVS) attempt to improve visual acquisition by enhancing significant components of the real world scene. Enhanced vision systems typically use imaging sensors to penetrate weather phenomena such as darkness, fog, haze, rain, and/or snow, and the resulting enhanced scene is presented on a Head-Up Display (HUD), through which the outside real world may be visible. One of the principal problems with EVS applications is the requirement to extensively train the pilot to deal with the visual artifacts present in sensor images.

The second two workshops were focused on the specific application of those pathway formats to the eXternal Visibility System (XVS) of the NASA High-Speed Research (HSR) Flight Deck Systems Program, which was concerned with replacement of the forward windows in a High-Speed Civil Transport (HSCT) with electronic display media and a suite of imaging sensors (i.e., an external visibility system). The purpose of the XVS was to enable a "No-Droop" configuration of the HSCT. The "No-Droop" mission of the XVS was defined as that system which, in a HSCT, would support routine airline operations in environmental conditions and at facilities equivalent to current subsonic transport capabilities, without the requirement to articulate the forebody geometry for ground operations, takeoff, approach and landing. The XVS primary flight display relied on a high resolution video camera image of the outside scene, with overlaid symbology. The display was somewhat analogous to that of an EVS, except for the lack of a collimated HUD. Also, the real world was not visible through the HUD imagery, and the sensor image was not from a weather-penetrating sensor, but rather from a visual spectrum camera. The purpose of the pathway formats within the XVS display was to enable highly-precise flightpath control.

The primary symbology concerns in the XVS application were the prevention of display clutter and the potential for obscuration of hazards, as the camera image in VMC and marginal VMC was the primary means of traffic separation. These concerns were not so prominent in the first two workshops, which assumed hazard locations would be known within the constraints of an SVS (from surveillance sources), and therefore obscuration would be handled easily.

The resulting consensus pathway concept that resulted from the September, 1996 workshop has been used since in simulation and flight test activities of NASA's High Speed Research (HSR) eXternal Visibility System (XVS), Advanced General Aviation Transportation Experiment (AGATE), and the Aviation Safety Synthetic Vision Systems programs, and other pathway concepts have been influenced by the workshop discussions. Among the direct users of the Langley workshop software are Boeing - Seattle, Boeing Helicopter - Philadelphia, the FAA-CAMI, the Research Triangle Institute, Wright-Patterson Air Force Base, and Rockwell-Collins.

Contents

Workshop # 1
April 25-27, 1994

Invitation to Workshop # 1

The Cockpit Technology Branch, Flight Dynamics and Control Division at NASA Langley Research Center is sponsoring a Pathway-Based Flight Displays Interactive Workshop on April 25-27, 1994 in Hampton, VA. The purpose of the workshop is to gain a better understanding of synthetic vision pathway displays & symbologies by having the subjects participate in an interactive workshop environment. The subjects will fly several pathway concepts for a generic approach task and make suggestions that may be iteratively implemented. During the iterative programming efforts, other display issues will be discussed, such as High Speed Civil Transport (HSCT) display real-estate usage and other flight phase displays (cruise, surface operations, etc.). Several pathway concepts will be available as a starting point, including various goalpost, roadway, and tunnel concepts.

Attendees

Terry Abbott	NASA LaRC
Tony Busquets	NASA LaRC
Gordon Hardy	NASA ARC
Randy Harris	NASA LaRC
Dave Hooper	American Airlines
Patricia Hunt	NASA LaRC
Walt Johnson	NASA ARC
Simon Lawrence	US Air
Paul Leckman	Boeing
Dean Nold	NASA LaRC
Mike Norman	McDonnel Douglas
Russ Parrish	NASA LaRC
Dave Regal	Boeing

PATHWAY WORKSHOP AGENDA
Bldg 1298, Room 103

- Monday, April 25, 1994 (8 a.m. – 4 p.m.)
- Welcome / Purpose / Agenda
  - Suggested Procedure (evolutionary from there)
  - Discussion of Aircraft Model
  - Discussion of Initial Symbology Sets
  - Discussion of Initial Tunnel Sets
  - Demo VISTAS & Some Synthetic Vision Capabilities
  - To Work (fly / talk / iterate)

- Tuesday, April 26 (8 - 4)
  (more of the same)

- Wednesday, April 27 (8 - 4)
  - Still More
  - Summation & Thanks

PURPOSE:

- not to arrive at a "best" format
- to just informally try different things iteratively to help us arrive at a better understanding of synthetic vision pathway displays & symbology sets
- to fill programming time gaps with HSCT discussions concerning
  - display real estate useage
  - other flight phase display concepts
    - » takeoff, cruise, surface ops
    - » descent / ascent

PROCEDURE:

- Fly It
- Talk About It
- Change It
- Fly It Again
- Change It Again

AIRCRAFT MODEL:

- Generic Medium Transport
- Linearized About Full Flaps/Gear Down
- Rate Command/Attitude Hold

SYMBOLOGY SETS:

- Flight Dynamics HUD
- 3 Predictive Gamma “Seagulls” (0, 3, 6 sec)
- Chevrons

TUNNEL SETS:

- Goalposts (path-fixed)
- Tiles (path-fixed)
- Grunwald / Ellis / Dorighi Sliding Square Tunnel (path-fixed)
- Boeing-like “Noodle” Tunnel (nose-fixed)
- Follow-Me Airplane (nose-fixed)

Pathway Workshop # 1 Minutes & Discussion Items
April 25-27, 1994
R. Michael Norman
McDonnell Douglas Aerospace

1. One topic of focus for the discussions was the need for pathway information, and the definition of a pathway. A pathway gives status information concerning the present, planned, or expected flight path.

2. Navigation Display (ND), and Primary Flight Display (PFD) information will probably be integrated in the primary Forward Visibility System display (FVSD). ND and PFD display elements should be reviewed to ensure that no loss of data sources occurs in integrating the data.

3. The methodology for integration of imagery in the display must also be considered, and may alter other display elements.

4. Several methods of declutter have been used previously, including physical separation selectable declutter, color, contrast, brightness, and depth separation in 3-dimensional displays.

5. There are two primary reasons to declutter displays - to reduce information saturation, and to reduce crowded areas of display to permit faster identification of critical display information. Declutter requirements may change with display scaling, physical size and field of view, and the presence of sensor imagery.

6. There may be a need, in presenting pathways, of distinguishing cleared flight paths from expected flight paths.

7. Several initial types of flight path "tunnels" were reviewed. The Dorighi Tunnel is defined by four dotted lines at the edge of an acceptable error box, with square guidance symbols inside the dotted lines, and a reference solid box at a fixed time reference ahead of the aircraft. The "Noodle Tunnel" is defined by a series of boxes, leading from the present aircraft position to a reference position on the cleared path, or final approach fix. The NASA Langley Goal Post Tunnel is defined by partial boxes consisting of side and bottom segments, center pillars extending from the bottom of the boxes to the terrain floor, and rectangular tiles inside the boxes defining the path to be flown.

8. Two primary types of guidance were discussed - standard flight director, and pursuit guidance. The standard flight director, as it is generally implemented, has a limited field of motion within the display, and provides some amount of lead steering in returning to a desired flight path following errors. Pursuit guidance, as implemented by NASA Ames, is represented by a "ghost aircraft," flying a fixed time interval ahead of own aircraft, on the desired flight path. Superimposing a velocity vector on

a reference mark on the ghost aircraft, then, provides pursuit guidance to the desired flight path, resulting in an exponential decrease in flight path error with time. The ghost aircraft is allowed to move throughout the display, with consideration for display element priority and pegging of guidance cues.

9. The need for color standardization was discussed, keeping in mind that both PFD and ND information would likely be combined on the FVSD.

10. The need for conformality was addressed. Conformality is defined as the property of a display wherein display element movement has a one-to-one correlation with the outside world, both in scale and position. Lines drawn from the pilot's eye to display features, if extended outside the aircraft, would then intersect the corresponding real world features. Conformality has been shown to be useful in direct view displays (Head-Up Displays, for example), but is generally not a feature of standard instrument displays. Concerns were expressed for the interaction between the FVSD and the side windows if the FVSD was not conformal, particularly during the flare. This item needs further simulation and study to resolve.

11. Error gains (the amount of display scaled displacement for a given error) will likely have to be tuned for a specific set of handling qualities for an aircraft. Since significant changes in flying qualities will occur with changes in altitude, speed, aircraft configuration, and flight control mode, error gains will have to be tuned for all of these considerations in the HSCT.

12. After initial evaluation by all of the pilots present, the consensus was that the "Noodle Tunnel" had little to no merit for the HSCT application, and was evaluated further. Since the beginning of the tunnel was always tied, laterally and vertically, to own aircraft position, this tunnel provided no cues to path error, merely showing a route back to the desired path.

13. Several of the pilots objected to the amount of clutter in the Langley Goal Post Tunnel, particularly early in the approach, where numerous goal posts could be seen.

14. It was generally agreed that the edges of the tunnel should correspond to the allowable error tolerance in flight path control. Some method for discerning desired error tolerance should also be provided.

15. One problem with pursuit guidance was discussed, in that during turns, this guidance will lead to flying to the inside of the turn, or cutting the corners. Two solutions to this problem were addressed deliberately positioning the ghost aircraft to the outside of the turn by a programmed amount, or providing a second order correction to the position of the velocity vector on the display during turns. The latter method has the advantage of also providing a more accurate prediction of aircraft future position in turns, at the expense of a somewhat more active display cue, unless damping is included.

16. Critical guidance symbology, such as the velocity vector or the pursuit aircraft cue, should never be allowed to disappear off the edge of the display. Some method should be provided to indicate the extrapolated position of the cue, as well as the fact that the cue has pegged on the display. Methods which could be used include freezing the cue at the proper position on the display (in a line to the actual position), flashing the cue, changing colors, hiding half or a part of the cue, or dotting the display lines constituting the cue. The method used for this study was to change the cue color to red.

17. Initially, the flight director cue changed from the pursuit aircraft to circular flight director cue at 200 ft AGL. This change in symbology near to touchdown proved distracting, and the cue appearance was changed so that it remained as a "ghost aircraft" throughout the flare and touchdown. NASA Ames reported successful use of a shadow cue oriented around the ghost aircraft in the flare. We were not successful in this workshop, however, in implementing the shadow cue in any acceptable manner, as attempts resulted in a distracting, cluttered flare cue.

18. The speed and acceleration cues implemented earlier by NASA Langley were well liked, and have been used successfully in other displays. NASA Ames reported that these types of cues provide an excellent early indication of impending windshear events, in instances where the acceleration and speed error cues move in opposite directions.
19. Discussions occurred on how to differentiate the runway cleared to on the pathway, in airports where multiple runways must be presented. One method mentioned was to outline the runway graphics with a highlight cue (purple, in the case of the workshop software). This highlight cue could also be used to indicate to the pilot that sensor position correlation had occurred, providing an added degree of confidence in displayed runway position.

20. Discussions occurred on the philosophy of manual or automatic landing modes as the primary method used. Difficulties may arise in pilot proficiency if automatic modes are considered primary, with manual pilot backup. In a reliable system, pilots could go for years, never having made a manual landing, and then suddenly being required to take control in an anomalous situation. It was suggested that a baseline assumption should be that the aircraft systems should be certified in all conditions for either manual or automatic landing modes, leaving the policy of when to use either mode to the customer. Even in manual modes, of course, it is likely that a significant amount of flight control augmentation will be provided.

21. During automatic ILS-guided landings in VMC conditions, concern was expressed regarding beam protection. During VMC conditions, ATC is not required to provide the same level of ILS beam protection (through aircraft separation) normally provided in instrument conditions. In present transport aircraft, crews can see other aircraft on or above the airport, which might contaminate the beam during

approaches in these conditions, and anticipate the need to take over manually, should beam deviations become severe. Some corollary to this information source, normally gained through forward facing cockpit windows, should be provided.

22. It was reiterated that, with the absence of direct forward views of the runway or airport, navigation and display systems accuracy and integrity are critical to flight safety, and must be assured and protected.

23. It was suggested that the presence of pathway display elements should be selectable by the pilot, so that information saturated displays could be decluttered when workload becomes high. Path error information should, of course, always be available in some form.

24. Concern was expressed that, since a pictorial forward display would replace the traditional PFD, it must be an all-attitude (spherically unconstrained) display. Provisions should exist to aid the pilot in unusual attitude recovery.

25. Two types of information should be provided on the forward display - pathway or position error (three or four dimensional), and flight guidance cues. The guidance cues should be simple enough that in high workload situations, the pilot is guided quickly on where to position the aircraft attitude and thrust (as applicable). Pathway or position error cues should be easily interpretable, and ideally should provide desired, as well as allowable, tolerances in the display element. Initially, traditional crosshairs were provided around the velocity vector to indicate desired path error limits. Later, these were replaced by a dotted box that was positioned in relation to the velocity vector so as to indicate lateral and vertical path error. The dotted box was preferred over the crosshairs, in that it decluttered the critical area immediately around the velocity vector, and was more easily interpreted than the crosshairs. Some pilots, however, still wanted analog error scales (similar to ILS raw data indicators) at the edge and bottom of the display. An additional digital display, indicating path error in equivalent "dots", was provided adjacent to the analog scales, which some of the pilots felt was a valuable addition to the display element. Concern was expressed, however, that these scales would interfere with altitude and/or velocity tapes on the display, particularly in high crosswinds. Further study is warranted to reduce the size of the analog scales, and move them to a location where they will not interfere with other display elements. It was also suggested that the scales and error box should be individually selectable by the pilot, as desired.

26. The question of whether or not cross training to and from other aircraft should be considered was discussed. The advantage of emphasizing cross training issues in the design is ease in pilot transition to and from other types of aircraft. The disadvantage is possible compromise of an unconventional but effective design strategy, in favor of a more conventional but less effective one, to reduce training impact. Of note, this issue was not a driving one, apparently, on the Concorde aircraft, and pilots transitioning to that aircraft typically remain there for the remainder of their careers.

27. The issue of velocity centered, vs. attitude centered, displays was discussed. In a conventional (attitude centered) aircraft display, the aircraft waterline, or reference mark is fixed on the display, and the velocity vector moves on the display in response to inertial velocity vector changes. In a velocity centered display, the aircraft velocity vector is fixed on the display, and the attitude reference allowed to move in response to velocity vector changes. Research has been conducted which suggests some benefits to the velocity centered display, particularly in high or gusting crosswinds. Some concern was expressed about pilot disorientation in the velocity centered display, since it is necessarily not a conformal display in crosswinds. Further study, both in simulation and in flight tests, is warranted to investigate the suitability in each strategy, velocity and attitude centered, for the HSCT mission.

28. A discussion occurred on whether or not to provide a pathway display element during constant heading flight modes, or during cruise modes in general. This evolved into a discussion, again, on what constitutes a pathway. The consensus among the group was that a pathway is defined three dimensional line in space, consisting of curved and/or straight segments, over fixed earth-referenced coordinates. Pathways could also have a time critical dimension associated with them, during 4-D clearances. This definition is consistent with what is presented on FMS map displays in current aircraft. Constant heading modes may not fit this definition, (excepting vectors away from or toward a defined path). It was suggested that pathways not routinely be displayed in constant heading modes, then, due to difficulties in display or interpretation of lateral flight path errors. It was also suggested that pathways, in general, be a pilot selectable display element, so that they could be removed in situations where they would be confusing, or clutter the display.

29. The issue of how to display a two dimensionally constrained pathway was discussed. This situation would occur, for example, during climb or cruise/climb. Here a cleared route over the ground would exist, along with an expected altitude at the end of the segment, but no specifically cleared vertical path would exist to get there (though a planned profile would be continuously computed). It would not be appropriate to display a three dimensional pathway here, since following minor vertical path errors, the pilot would not be expected to return to the previously computed optimum performance path, and a new optimum performance path would continuously be computed. The distinction between path and guidance information should be stressed here - the pathway does not indicate how the pilot should reduce path errors (guidance cues do that), it merely displays those errors. It was suggested that when pathways are laterally, but not vertically constrained, the displayed vertical error should be zeroed at all times. The pilot, then, could fly laterally off the path, but never above or below it. The practicality or useability of this display philosophy remains to be demonstrated.

30. Additional note was made of the facts that the HSCT will probably not be in level cruise as much as subsonic aircraft (HSCT expected benefits of cruise/climb modes

are more significant), and that cruise clearances will likely involve tight lateral tolerances, due to sonic boom constraints. Two dimensionally constrained paths, then, must be considered when developing display modes and formats.

31. Concern was expressed that these 2-D constrained paths may have to be altered quickly during unplanned configuration or performance changes, as in an engine failure following takeoff, or early flap extension or retraction. The effects of these rapid display changes should be investigated in conjunction with display development .

32. The idea was suggested that navigational waypoints could be displayed as three dimensional objects on the display. This idea was implemented on the LaRC Visual Imaging Simulator for Transport Aircraft Systems (VISTAS).

33. A discussion occurred concerning the difference between guidance and pathway information. It is entirely conceivable that guidance cues may lead the pilot away from the pathway, as in a brief vector off course, for instance. One suggested philosophy was that a pathway be displayed when a route segment has been entered or computed in navigational planning systems (as in an FMS route in today's systems).

34. The display of four dimensional pathways (those which include time constraints) will probably require both status and guidance display elements relating temporal errors. Two predominate philosophies exist relating to time constraint guidance - speed control, and volume clearance. In the speed control philosophy, speed commands are issued to conventional display elements (command airspeed or airspeed error) to keep the aircraft in the center of an allowable time error band. This philosophy suffers the disadvantage of demanding too tight a control in some occasions, at the expense of reduced performance. Another method suggested was the space volume clearance method. In this philosophy, there is a volume of space which moves with the aircraft that represents the edges of allowable error tolerance (how far the aircraft can deviate from optimum and still make required time constraints at a reference waypoint with acceptable speed adjustments). The volume clearance philosophy, it was reported, allows more flexibility in speed control, and may result in greater fuel efficiency. Guidance cues could consist of changes in perspective distance with respect to a pursuit aircraft, or color changes on a pathway. Further study is warranted to develop appropriate cues for four dimensional status and guidance display elements. Of note, these may be difficult when the desired clearance volume is behind the aircraft.

35. The idea was expressed that pathway information displayed on a pictorial forward display should be redundant with respect to information displayed on other navigational displays (the ND, for example). Pilots should use ND's it was suggested, primarily for flight planning, path verification, and vertical path perspectives. The pilot should not have to refer to an ND for guidance to a path, or a

path error status. Discussions suggested that in addition to route or navigational data, terrain clearance, terrain presence, and weather information are other information categories that should be redundant.

36. A discussion occurred concerning the requirement for three dimensional weather depiction on a pictorial forward display. Questions arose on weather or not the pilot needs vertical cell location on this type of display. The consensus appeared to be that the pilot does need this information, both in JMC and VMC conditions, to aid in guidance over storm cells or systems.

37. It was suggested that, in addition to a perspective oriented pictorial display, and a horizontally oriented navigational display, the need exists for a vertically oriented profile display. This display would present a side view of the aircraft and flight path, and would show vertical position and deviation from a reference.

38. The need to show missed approach information on the forward pictorial display was discussed. During approaches, the pilot will need this information, both to help plan for flight path requirements, and to visualize the projected flight path with respect to terrain, other waypoints, airport references, etc., in the event of a missed approach.

39. The possibility of embedded flight training was discussed. Embedded flight training is training which can occur during a flight, ostensibly during extended cruise segments, where a portion of the aircraft systems acts as part task flight simulator, to train pilots on systems, procedures, or maneuvers. This idea is popular in advanced military aircraft. Further analysis and trade studies are warranted.

40. Clutter was emphasized as an important issue in forward pictorial displays. It was also emphasized that clutter may have a different meaning in a display wherein elements are intended to replace outside world cues. Clutter, for example, may lead to information saturation in portions of a display, if not properly considered. Clutter should never, however, lead to deliberate obscuration of critical information components of a display, as contrast, brightness, or occultation are legitimate tools available to prevent this. Pixelation and display resolution are parameters mentioned which may affect pilot perception of clutter.

41. It was mentioned that the VISTAS display resolution is 1.5 arc minutes - essentially equivalent to human 20/20 vision. Questions were raised whether or not this resolution is reasonable in displays of the type and vintage under consideration, including the time required to convert prototypes to flight ready systems.

42. It was noted that requirement for forward visibility systems might be considerably different in VMC than in IMC. VMC is probably the more technologically demanding of the two, and should probably be addressed first, it was suggested.

43. Problems with displays during taxi were discussed. It was mentioned that present technology would allow detection and tracking of surface vehicles and people through the use of Airport Surface Detection Equipment. Relatively inexpensive (75 cents was quoted) tags would allow objects to be tracked, and data linked, to aircraft operating on or near the airport. Significant objects could then be displayed appropriately in the cockpit. Problems of animals on taxiways, or snow banks in the Winter, were additional items mentioned which will have to be addressed.

44. The need was discussed to ensure that space is left on the forward pictorial display to present engine, and other systems information. It was mentioned that perhaps an auxiliary display could be provided to indicate this information, adjacent to the main display, and shared between the crew. A list of information requirements, to be presented on each type of cockpit display, is needed.

45. The need for color standardization in display elements was discussed. Cleared flight paths, for example, are traditionally displayed in magneta on FMS map displays, and should probably be displayed in that color on pictorial displays. Proposed, or alternate flight paths could be displayed in white, using lack of brightness, dotted lines, or suppressed resolution to distinguish them as planned paths, on pictorial displays.

46. The problem of indicating cleared, vs. planned, altitudes, was mentioned. For example, a descent route segment may begin at Flight Level 350, end at 5000 feet MSL, but the aircraft is only presently cleared 15,000 feet MSL. One method suggested of indicating this in path data was to present a pseudo cloud deck, or translucent tiles, at the cleared altitude on the display. Further study is warranted to arrive at an acceptable method of display.

47. The issue of what types of altitude and airspeed situational awareness information to display was mentioned. Classic types of display elements include tapes, digits, rolling digits, and analog dials. Keeping in mind that the primary purpose of these display elements is situational awareness only, studies are warranted to arrive at an acceptable means of presenting these display elements.

48. Additional capabilities or features were requesting in the VISTAS display which were not incorporated yet. They included a full takeoff, climb, cruise, descent, approach, and landing profile, the ability to alter landing gear and flap/slat configuration, functioning rudder pedals, and an HSCT representative aero model (see Steve's List below).

49. It was suggested by NASA representatives that the uniqueness in capability of the group, and the value of the issues raised to high speed research significant enough, that the FVS workshop should not be limited to just one session. It was suggested that the group meet again in September, 1994, for further refinement of issues and candidate solutions to problems raised.

Steve Williams' List

Steve,

Even though I know how you use/don't use lists, here is mine on what remains to be done for the Sept. workshop:

1. Rudder software fix

2. Retiming the taxi -- hold-short aircraft

3. Retiming the traffic to the other runway

4. Reworking the xdot/throttle equation & autopilot closure loop

5. Calculating airspeed/altitude relation

6. Flare command localizer transition

7. Flare command gamma tuning

8. Missed Approach Path *

9. 4-D concepts (wing span, tunnel color shading, etc.)

10. Soft Path concepts

11. Multiple paths (cleared vs. expected __ example is "expect direct from waypoint alpha to waypoint bravo")

12. Turning wind off after weight on wheels signal

Russ Parrish

* Mike Norman says that the FMS guidance for most airports has a missed approach fix about .5 Nmi from the runway end on the centerline at a certain altitude (say 1100 ft AGL) from which you are to begin a standard rate turn to the reentry waypoint track. How about a STAR for the workshop similar to the attached figure ?

Dave Hooper's Suggestions for the Sept. workshop **Sept.9, 1994**

Symbolic colors

Although we have, thus far, succeeded in decluttering the display area I still feel a need to assign various color attributes to specific symbols. The following is my initial list of suggested color assignments:

Approach Window Yellow
Flight Path Vector Ind Magenta
Pursuit Aircraft White
Indicated Airspeed Tape White
Radio Altimeter White
Roll Scale White
Aircraft Reference White
Pathway Tunnel Green
Goal Posts Green
Pitch Scale White
Horizon & Heading Scale White
Actual Heading White
Selected Heading Green
Fast / Slow Indicator White until +\- 10 kts then flashing yellow

Wind Vector

I would like to see the wind vector and speed indicator moved from the ND to the PFD in the top right corner as it is displayed in the original Flight Dynamics HUD. VS / GS / IAS

Some of my photos of the past workshop show indications of IAS over GS on the left and MSL over RA with VS below , on the lower right side of the PFD. Other photos show this data removed. I think this data is needed and a discussion concerning the position and amount of information would prove beneficial.

Glide Path Angle

I would like to see a printout of my current glide path angle ie. 3 degree to match a 3degree glide slope.

Touchdown Point

I might like to see either a graphic profile or digital readout of where I will touchdown on the runway with reference to my flight path vector. This would be in relation to the desired touchdown point.

Pursuit Aircraft

This summer Walt Johnson was able to provide me with an opportunity to fly the Vertical Motion Simulator with the HSCT mockup. Every time I performed a go- around, the

Pursuit Aircraft would disappear and I would be left flying raw data. This is workable, however the transition to raw data was abrupt and not desirable. This transition was probably due to the computer program. I suspect that the go-around routines had not been written yet. I would simply like to be assured that the pursuit aircraft will eventually be a full time display. This should also include a readout of the mode which the pursuit aircraft is currently operating. ie. Approach, go-around, cruise, climb, descent, vertical nav climb/descent, VS, windshear escape, engine out go- around, etc. The pilot needs to know where the pursuit is taking him, and why.

Approach

I think that we need to discuss when the approach mode will begin and end. Once this is done we can decide what symbols need to be displayed on the PFD. ie. goal posts, approach window, CDI information, radio altimeter, etc.

Visual Cues

In the real world I receive visual cues which alert me to the actual flying conditions. For example, I might see black clouds, lighting, virga, and heavy rain. These cues would alert me to the possibility of microburst activity and thus I would be mentally alert for this type of flying. On another day I might see blue sky, sun, and have a visibility of 60 miles. With these cues I would be more relaxed and more concerned with VFR traffic than microburst activity or thunderstorms. During one of my approaches in the VMS I was presented with microburst activity on short final. I was told that this would occur, so I was ready for it, yet something bothered me about this scenario. It wasn't until I returned home and began to ponder this question that I discovered that I was missing the visual cues of microburst activity. The synthetic vision was that of a great day with blue skys and no weather. My visual cues told me that there was not much to worry about. They said, "take it easy and concentrate on making a good landing." The only cue I was provided with was when they told me that I was going to encounter a microburst. That won't always be the case. Sure I will have the side windows, weather radar, and hopefully some type of terminal doppler weather radar, but will that make up for the loss of real time visual cues that we unconsciously rely upon today? I don't mean to insinuate that I must be provided with an advanced warning of a pending situation in order to be able to fly safely. Pilots have a long history of adapting to rapidly changing conditions. This is one of our specialties. However, by providing us with visual cues of one situation while we are actually encountering totally different actual conditions is very misleading and unnatural. I would like to have an open conversation concerning this loss of visual cues.

Track vs. Heading

I once was a believer in the "heading up" concept. Then I flew the B-767. Now I am a true believer of the "track up" concept. Yes, I need to know what my heading is, but as far as navigation is concerned, I need to know my track. We need to discuss this concept and begin to evolve a direction.

CDI

I like the Approach Window, or ILS Box, concept. However, when we strayed off course far enough, and it will happen, the window slid completely off the screen leaving us with no direction back to the final course. Then we added course deviation indicators which included a great idea from Steve Williams (I think). He added a display of the number of degrees you are away from the localizer or glide slope. This addition was great because you could easily determine if your current heading was bringing you back to your desired course/path, or not. The CDI's do, unfortunately, create clutter. So I would like to propose that the CDI information only be displayed when you are so far away from the desired path that the approach window is no longer in view.

Roll Scale

If the Roll Scale only displays bank information up to a max of 30 degrees, then how will we practice 45 degree bank turns? Why not present a digital readout of all banks in excess of 30 degrees?

HDTV

As you know there are going to be many problems created with no forward looking windows. Could we have additional discussions concerning a full time HDTV display. If we are going to discuss cockpit real estate, we will need to save room for this display.

Nav Display

The ND must have some type of taxi display similar to the TEEM (Taxi Evaluation Electronic Map) display. The ND will also have to display radar information superimposed over our route. I would also like to see the ND used in the "track up" mode with a heading line from the aircraft symbol to the selected heading, like the B- 767.

Vertical Navigation

This area of display and programming needs to be discussed.

Workshop # 2

September 20 - 22, 1994

Invitation to Workshop # 2

We are planning our second interactive workshop on pathway displays for Sept. 20 - 22, 1994. We again anticipate beginning at 8AM on the Tuesday and winding up about mid-day on the Thursday. The idea is to have the participating pilots fly several pathway concepts and to have all participants make suggestions, which we will try to implement "then and there" so they could iteratively help us arrive at a better understanding of synthetic vision pathway displays & symbologies. While Steve Williams is programming away, we would be discussing other display issues, such as HSCT display real estate usage, other flight phase displays (cruise, surface ops), etc. We intend to have the following available as starting points: velocity-centered vs. attitude-centered displays, multiple-displayed pathways (approach & missed approach, cleared & expected), soft pathway concepts (unspecified in at least one spatial dimension), 4-D pathway concepts, flight phase transitions (cruise to descent, etc.), other flight phases (takeoff, cruise, etc.). We have invited the following participants:

PATHWAY WORKSHOP INVITEES

PILOTS

BOEING
Paul Leckman

AMERICAN AIRLINES
David Hooper

HUGHES & DELTA AIRLINES
Bob Blanchard

NASA AMES
Gordon Hardy

DOUGLAS
Mike Norman

U. S. AIR
Simon Lawrence

FAA
TBD

NASA LANGLEY
Lee Person

RESEARCHERS

BOEING
David Regal
HSR FVS Representative

HONEYWELL
HSR FVS Representative

NASA AMES
Walt Johnson

HUGHES
Sam Hollingsworth

NASA LANGLEY
Terry Abbott
Anthony Busquets
Dale Dunford
Patricia Hunt
Randy Harris
Dean Nold
Russ Parrish
Steve Williams

As you see, we are inviting more HSR FVS representatives this time, as our fears that too many participants meant too many cooks in the kitchen proved unfounded last time. We invited only known pathway researchers, rather than any folks with those interests. Anyway, I hope you can come. Let me know if there are any problems.

Regards,
Russ

PATHWAY WORKSHOP ATTENDEES

PILOTS

BOEING
Paul Leckman

AMERICAN AIRLINES
David Hooper

HUGHES & DELTA AIRLINES
Bob Blanchard

NASA AMES
Gordon Hardy

DOUGLAS
Mike Norman

U. S. AIR
Simon Lawrence

FAA
Berk Greene
George Lyddane

NASA LANGLEY
Lee Person

RESEARCHERS

BOEING
David Regal
Brian DeLuca

NASA AMES
Mary Kaiser
Charlie Hynes
Dick Bray

HONEYWELL
Mike Johnson

HUGHES
Sam Hollingsworth

NASA LANGLEY
Terry Abbott
Anthony Busquets
Dale Dunford
Patricia Hunt
Randy Harris
Dean Nold
Russ Parrish
Steve Williams

Collins
Tom Sharp

FAA
John Hickey
Howard Greene

PATHWAY WORKSHOP #2 AGENDA

Bldg 1298, Room 103
NASA Langley

- **Tuesday, Sept. 20**
  - Welcome / Purpose / Agenda
  - Suggested Procedure (evolutionary from there)
  - Discussion of Aircraft Model
  - Discussion of Initial Symbology Sets
  - Discussion of Initial Tunnel Sets
  - Demo VISTAS & Some Synthetic Vision Capabilities
  - To Work (fly / talk / iterate)

- **Wednesday, Sept. 21**
  (more of the same)

- **Thursday, Sept. 22**
  - Still More
  - Summation & Thanks

PURPOSE:

- not to arrive at a "best" format
- to just informally try different things iteratively to help us arrive at a better understanding of synthetic vision pathway displays & symbology sets
- to fill programming time gaps with HSCT discussions concerning
  - display real estate useage
  - other flight phase display concepts
    - » takeoff, cruise, surface ops
    - » descent / ascent

PROCEDURE:

- Fly It
- Talk About It
- Change It
- Fly It Again
- Change It Again

AIRCRAFT MODEL:

- Generic Medium Transport
- Linearized About Full Flaps/Gear Down
- Rate Command/Attitude Hold

SYMBOLOGY SETS:

- Flight Dynamics HUD
- Predictive Gamma "Seagulls"
- Chevrons

What's New ?

- MODEL CHANGES
  - Active Rudders, Flaps, & Gear
  - HSCT-Like Approach Characteristics
  - Other HSCT-Like Flight Phases & Transitions
  - Mode Control Panel
  - Wind Off After Squat

- Can Demo Velocity-Centered vs. Attitude-Centered Concepts
  (Actually, The Fixed Reference Point Doesn't Have To Be Centered)
- 4-D Concepts (Both Volume & Speed Types)
- Multiple Paths (Cleared & Expected)
- Multiple Paths (Approach & TOGA)
- Soft Path Concepts (Unconstrained Lateral, Unconstrained Vertical)

TUNNEL SETS:

- Goalposts (path-fixed)
- Tiles (path-fixed)
- Grunwald / Ellis / Dorighi Tunnel (path-fixed)
- “Noodle” Tunnel (nose-fixed)
- Follow-Me Airplane (nose-fixed)

Group Recorded Items from 1st Meeting

- Purpose of Pathway
  - Provide Think Ahead Information
  - Provide Corridor Representation
- Don't Want Pathway When
  - No Ground-Based Constraints
  - Pathway Would Conflict With Guidance Information
- Might Want Pathway When
  - FMS Has Two-Dimensional Path Information (Ground-Based)
  - FMS Has Three-Dimensional Path Information (Ground-Based)
  - TBD Reasons

Group Recorded Items from 1st Meeting

- Things to Consider
  - Path Discontinuities
  - ATC Radar Vectors/Heading Courses
  - Climb / Cruise / Descend Phases
  - Conformal / Non-Conformal (boresight vs. velocity-centered)
  - Emergency Path Revisions
  - Levels of Constraints (2-D vs. 3-D)
  - TOGA Path
  - Multi-Paths (Non-Active Paths)

Minutes from Workshop #2

Russ,

The following is a set of observations and comments regarding the workshop. But first, let me add that, at the risk of adding to the number of future workshop participants, I gave the workshop very favorable reports here at Honeywell.

Thanks again for the opportunity and the privilege of allowing us to participate. You and your staff put together an excellent forum for technical interchange, useful in general and especially useful for the upcoming HSR flight deck effort.

Sincerely,
Mike Johnson

Side windows
Many at the workshop seemed to feel that there would be no substantial operational difficulty incurred, if the side windows were eliminated from the HSCT cockpit. If the side windows were eliminated, many more candidate display technologies would become available. Only a few merit serious attention now. The maximum levels expected in ambient light and the sunlight shafting constrain us to just two or three high brightness technology paths. No side windows imply relief on high brightness requirements and on tough conformality requirements. Clearly, the presence or absence of side windows is of primary importance.

At the HSR quarterly meeting in Seattle this year (94), there was considerable sentiment evident that side windows should be retained as part of the baseline configuration. The rationale appeared to rest on two facts: 1) Some believe the side windows offer a significant if not high degree of utility and function not yet fully understood or characterized; and 2) Side windows present no major cost impediment to building a cost effective HSCT structure.

If the side windows were to be ultimately retained, it may be possible to limit the levels of ambient light and the sunlight shafting that come through. Overlaying the windows with a light valve or micro-louver or equivalent technology might suffice. Efforts in these areas have been recorded and indicate such approaches are feasible, depending on more detailed requirements specific to each application.

Risk assessment of the Pathway and Ghost Aircraft Format
This entry is to note that, from the standpoint of a display systems designer, pathway formats are low risk. Computational and storage requirements are modest. And, as noted by several at the workshop, precedents by similarity exist.

The HGS made by FDI does provide support for probable certifiability of pathway formats. The HGS portrays a simple 4 point perspective runway rendering that uses the same raw data the pathway uses. The principal difference is that the trend information is not calculated and shown in an HGS, although the raw data to do so is present. Similarity of pathway formats we observed in the workshop to existing PFD formats (a point that Dave Regal made) provides additional support.

The distinction between terrain database rendering and pathway rendering made by Dave Regal, Mary Kaiser, Brian DeLuca and others, is re-iterated here as being technically correct, at least as seen from the standpoint of a display systems designer. After the trend data are calculated from the raw aircraft state variable data, the fundamental problem is one of transforming world referenced coordinates to screen referenced coordinates. The PFD, the HGS and the NAV display formats are rendered from this type of calculation. I estimated there were about one thousand 3D vectors displayed on the pathway formats. The HGS shows two vectors. Although about three orders of magnitude more processing are needed, the types of calculations required are within the realms of current single processor capability. The amount of database storage needed is the same as is required for the HGS, which is negligible. A table showing changes in database and processor throughput requirements could be constructed to show detailed and objective comparisons.

Object detection and display resolution

If object detection by machine is equal to or better than object detection done by the human , then it may be possible to reduce resolution requirements on the HSCT forward display system. It may be acceptable to instate a lower than ideal display system that compromises 20/20 visual acuity (among other visual attributes). The machine may be used to annunciate the region(s) of interest. Then, the human operator might acknowledge the alert by directing the forward vision system to zoom in and magnify the area of interest so the human can identify the object and the level of threat. One TV (or HDTV or UHDTV) sensor may be gimbaled with respect to a matrix of panoramic and stationary sensors to acquire the area of interest and magnify it.

What is missing is the definition the "object" in the physical and operational HSCT context. For example, is an object always made of metal or at least highly reflective and of sufficient contrast in the radar spectrum? Or is it a contrast divot in the visual spectrum and, if so, is it in need of comparison with known objects in the geographic area and catalogued in a detailed database? Definition of the term object must be made in terms of the physics (wavelength of the sensor, dynamics, reflectivity, transmissibility, signal to noise ratio, range of viewing conditions, ...) and in terms of human psychophysics (current level of object detection) and in terms of probability of success and false alarm and ease of control. Much of this is the subject of basic research in the physical and the psychophysical domains.

My own feeling is that object detection by machine will aid human vision substantially but may not reach the level of performance necessary within the timeframe of the "no droop" decision to warrant reduction of display resolution requirements. Early assessments of probability of success in this area are imperative.

Competition between symbology and background video

Haloing, a thin black border encircling all the high priority symbology, is designed to allow primary symbols to be easily discerned, regardless of the intensity of the surround. Easy discrimination of symbology will become especially important when the pathway is overlaid on a field of video. Video presents a wide range of intensity and color patterns making a priori color and intensity selections of the pathway symbols difficult to do unless an occlusion method is used. Steve Williams implemented haloing on formats shown the last day of the workshop. Video or a reasonable facsimile of it (perhaps photographically texture mapped terrain) is needed in future pathways workshops to adequately assess how the pathway will interact with the primary VMC sensor.

Mary Kaiser suggested in a side discussion that we identify ways of eliminating or reducing the risk of obscuring objects that might otherwise lie hidden beneath the overlaying symbology. That this is an area of legitimate concern is underscored by a story Mike Norman told at the HSR quarterly meeting last April. He stated that, on an approach during SVS flight tests, a truck parked on the runway lay unseen, hidden by a single vector displayed on the HUD, for an appreciable portion of the approach. Under actual VFR/VMC situations, flying in this mode could be a real problem.

We might rely on machine vision object detection to annunciate areas of risk, enabling the pilot/copilot to determine how they want the symbology to be displayed. This concept may, however, mandate the presence of a detailed database that includes an inventory of known objects. Hidden object display options might appear in a selection menu the viewer uses to choose how he/she wants the symbology and the object to be displayed.

Mary proposed that an additive or translucent method of annunciating the symbology be explored so as to test for ways of minimizing the obscuration of objects residing beneath symbols. Experiments that I did in this area some time ago showed that the underlying video and the symbol interfered with each other and both became difficult to "read". These experiments were informally executed using the "golden eyeball" approach. It may be fruitful to investigate ways of overlaying symbols on sample fields of video using a more controlled and formal procedure.

One bottom line question is, "How do HUDs in use today circumvent the problem?" The answer to that question may provide guidance here.

Database considerations

The database storage requirements for storing key runway locations is very modest to negligible, when compared with the storage requirements needed for storing elevation data. A few floating point numbers (lat and long of the runway centroid) and a few attribute codes (runway size class, azimuth, material class,...) are likely to be sufficient for rendering runway areas at the level of detail shown at the workshop. It is feasible using this or a similar method to encode all the nation's runways in a few EPROM chips.

In contrast, elevation data like that stored in a DTED Level I format requires something on the order of a 16 bit number every 93 (3 arc seconds) meters. At this sample spacing, five optical discs at about 680 Mbytes of storage each can store the elevation profile for the entire United States. By the time the HSCT go-ahead is given, chips with a gigabit of storage are projected to be widely available. This means that a few chips may be relied on to store even fine grained elevation profiles.

It is likely that the database structure will have a hierarchical arrangement, coarse to fine as the runway or terminal areas are approached. [DTED Level I carries a coarse sampling resolution that is widely thought to be insufficient for rendering scenes at or near the runway. Ten times finer spacing may be required along each of the major axes over the earth's surface. This implies about 100 times more samples total are needed but only in the terminal area. The impact on the total database may be minor.]

The real problem is the database infrastructure. Who will bear the cost of setting up a database with a flight critical level of integrity? And who will decide what goes into it and what gets omitted? And how will it be maintained?

Pathway goalpost extent and video

When the pathway is shown overlaid on a background of video, the goalpost may project to the nominal geometric plane of a flat earth despite the presence of rough and perhaps mountainous terrain. Adjusting the height of the goalposts so that they intersect the real earth volumes present in the video image may be difficult to do and certainly implies an elevation database or dynamic means of estimating elevation in real time.

To circumvent these difficulties, it is suggested that the goalpost extent remain unmodified and referenced to the geometric plane of the runway threshold. This should remain easy for the machine to render and for the pilot to interpret.

Later, when an elevation database is in place, the goalposts may be used to highlight CFIT hazards; color codes and/or flashing attributes may be applied to the post to annunciate the different levels of urgency.

Pathway versus entrenched flight director

Perhaps the wholehearted endorsement that the pathway format received at the workshop** makes this note unnecessary but I thought it incumbent on me to point out that existing graphics techniques might be invoked to eliminate all or an appreciable part of the concern. A memo by Dave Regal preparatory to the workshop highlighted the long-standing concerns about introducing pathway formats into the PFD arena.

I can go into more detail but the graphics concept is along the following line of thought: It is technically feasible to "grow" the pathway out of the traditional flight director using a control knob, or rocker switch or selection switch. The growth can be a gradual metamorphoses that happens under pilot control or it can be switched in by the pilot as a format option and enhancement. More detail will be provided if there is interest in this area. Whether this kind of approach is needed remains to be seen.

** I heard statements (paraphrased here) like: "The pathway is so much easier to use." and; "The pathway uses elements already certified." and; "The pathway is almost identical to the entrenched PFD along a number of important dimensions. It's not much different than a PFD."

Opportunity for pathway to convey hazard and constraint situation awareness
Mary Kaiser pointed out that the pathway format may provide opportunities for boosting situational awareness beyond the statistical centerline guidance walls. A subcommittee of the FAA, studying cockpit safety, recommended that cockpit display formats must communicate situational awareness more effectively than they do today. The subcommittee stated that the display format must indicate the location of hazards. It stated that the communication is increasingly important as the airspace grows more congested and flight path tolerances narrow. The objectives are to enable more effective and safer navigation while negotiating difficult terrain, parallel runways, tighter aircraft spacing, etc. Perhaps there is a way to augment the pathway, with its compelling pictorial display, to do just that.

Other Notes from Workshop #2

From: "Tom G Sharpe" CREMS.TGSHARPE@CREMS.ROCKWELL.COM

Comment re ghost aircraft guidance:
One observation, I think made by Terry Abbott, was that the "guidance" should be consistent for all flight modes. For modes like heading hold/capture, altitude hold/capture, using a ghost aircraft displaced from own aircraft flight path vector (FPV) to indicate guidance commands will appear to the pilot much like "chasing" the ghost aircraft down the tunnel even though the underlying "guidance algorithms may be quite different. The area where there may be an inconsistency at present in your setup is when the aircraft is outside the tunnel and on an intercept course. With your current algorithm, the ghost aircraft position is based on a perpendicular dropped from current aircraft position to the tunnel. In some ways this seems quite natural since one watches the ghost fly down the tunnel and simply "falls in behind him". However, if one is in a heading hold mode flying an intercept path with respect to the tunnel, the ghost should underlie the FPV if I am on the right heading and then should start demanding a maneuver in one direction or the other when I hit the capture trip point for acquiring the tunnel (i.e. it will not cross my path from one side to the other as it does now.) Another case is that one is in "tunnel track mode" and flies out of the tunnel. This case is a little less straight forward because it depends on the strategy adopted by the guidance algorithm for

returning one to the tunnel. As an extreme case consider flying away from the tunnel at 90 degrees - by the projection algorithm, the chase airplane would disappear from view since it would be behind you. It would seem that in this case either some kind of mode change should occur and be annunciated or the chase airplane should be in view and cueing me for a return to the tunnel. I don't have any final answers here - just the suggestion that this is an area that needs more work.

Notes on Pathway Displays Workshop #2
T.G. Sharpe
9/20/94; Revised 10/14; 10/19;11/3

GUIDANCE CUES

3D Trend Vector:

* 3 and 6 second (2,4,6 second ?) projected aircraft position

* Used gull wing (nose of aircraft) symbol

* Parrish claims can fly tunnel with this in lieu of guidance cue

* Dropped after first workshop because was thought to add clutter

Ghost Aircraft Guidance:

* Ghost aircraft leads "own" aircraft by 8-10 seconds in pathway

* If ghost aircraft flies down center of pathway, own aircraft tends to "cut" the corners

* Algorithm has ghost aircraft fly outside tunnel in turns so that own aircraft stays in the tunnel

* An alternate approach would be to have the ghost aircraft stay in the tunnel (i.e. not be compensated) and to track it with a "quickened" or acceleration compensated flight path symbol. This approach was not liked as well in a cursory evaluation ("too active"), but the implementation may not have been optimized. This approach may also pose problems when not flying chase or when trying to take crab out on landing.

* Coming toward the tunnel from the outside at an angle, say 45 degrees to the tunnel, the ghost aircraft appears to be to the left side of the flight path vector at first then moves to the right crossing the flight path vector. Falling into trail

behind it to capture seems a very natural maneuver. Note that the ghost is drawn 8 seconds ahead of the perpendicular to the tunnel dropped from own aircraft.

Ghost Aircraft Appearance:

* Concern was expressed that perspective ghost aircraft was overkill (and cluttering) when flying the tunnel, but useful when acquiring the tunnel; compromise was to show perspective aircraft when outside the tunnel, and simple circle guidance cue when inside the tunnel. not sure where this wound up??

* Need hidden line removal to improve appearance

* Original flashing "aim point" on tail of ghost was changed to a non flashing circle and flashed briefly as an alert just prior to flare.

* Lots of "white things" add up in the middle, make the ghost aircraft magenta.

4D NAVIGATION

Time Rails:

* Angle irons on front portion of tunnel to show status of time requirement

* Symbol represents 4 second interval; small right angle pointer in middle indicates exactly on time

* Symbol is normally amber with right angle in green; symbol turns yellow if right angle pointer leaves symbol but is between 4 and 6 seconds off and turns red if pointer is more than 6 seconds off

* Right angle pointer symbol pegs for fast but dropped behind angle irons for slow

* Suggested modification was to peg pointer symbol in both directions and to display time error digitally while pegged

* Originally autothrottle did not include time control; so speed trend vector and time rails were at times in conflict; this was later corrected

* Note that is very possible to get too far off in time to be able to recover (particularly in the fast direction) without deviating from the path (i.e. time eating diversion or cutting corners to save time); would be nice to have some way of indicating this condition

*   Should remove pointer from rails on final since at this late stage are not going to worry about managing time - "..from outer marker, you are not going to screw around with time keeping! (D. Hooper)"

PATHWAY SYMBOLOGY/PRESENTATION

Dorighi Tunnel:

*   Actually Dorighi, Ellis, Grunwald (of Ames)

*   Considered very low clutter; corners of square tunnel simply marked with four dashed lines

*   When off to the side; only 2 dashed lines are drawn to avoid distracting optical anomalies with 4 lines - sounds strange but seemed to work okay in practice

*   Several comments that "time rails" (see 4D Navigation above), although not intended for that purpose, dramatized the front end of the tunnel in a dramatic way

*   This tunnel avoids the difficulty incurred by many symbologies of having an accumulation of far off symbols adding up to a very bright center in the tunnel

Soft Pathways

*   Idea here is how to handle pathway displays when constraints are soft or there are constraints in one axis but not the other

*   Lots of discussion, no consensus

*   Pathway is not appropriate for all cases; pathway is "attached to earth" in normal viewpoint so doesn't work for heading hold, performance climb or descent, etc. which are not tied specifically to earth although they may have to be accomplished in some volume constraints

Meaning of Tunnel/Tunnel Characteristics:

*   Meaning of tunnel walls - this came in for a lot of discussion. e.g. what is consequence of going outside the tunnel - sometimes trivial, but if tunnel is to avoid terrain, going outside could be catastrophic. On final approach tying the tunnel to the emerging "tunnel" certification criteria seems logical but further out and enroute things are much muddier. Flight corridors, e.g. across Atlantic are set wide to account for navigation errors. {The tunnel width should reflect what the pilot should stay within so that the sum of his path following errors and the navigation imprecision keeps the aircraft in the required corridor (my input)}

* A/C should move through tunnel rather than push tunnel ahead of it

* Need to be careful in mixing perspective and non- perspective symbology; okay to do just need to be careful

* Lots of discussion concerning whether tunnel should show that "busting the tunnel " in one direction may be more hazardous than in the other - consensus was that tunnel shouldn't try to show this - current industry philosophy does not distinguish cost of violating a constraint (e.g. really dangerous versus sort of dangerous)- continuing concern about how to define the tunnel boundaries.

* When should tunnel disappear - at 50 ft, 100 ft, ?? consensus was question should be determined in simulation; similar question on angle irons or rails

* Another reason for close tolerance on approach tunnel is that it improves the touchdown footprint

Noodle Tunnel

* Front end of tunnel remains fixed to aircraft as one maneuvers while far end remains anchored

* Pilots did not like; "tunnel kept whipping all over"

* Might have applicability to soft pathways

Field of View

* Parrish has compared FOV for pathway displays; 70 deg FOV is much preferred over 40 deg but performance differences were very minor

* All of this pathway stuff was shown on a 70 deg FOV HDD (VISTAS) or on a 40 degree projected outside scene; almost everyone used the projected scene because it was more attractive in appearance due to simulation artifacts on head down presentation.

OTHER SYMBOLOGY

Velocity Centered Display

* Normal presentation is "attitude centered", i.e. the gull wing, or nose of the aircraft is fixed on the display and the other objects move, importantly in this case one can never lose the pitch indication since the gull wing and pitch tape are always on the screen.

* Velocity centered(VC) is based on idea that "everything is happening around the flight path vector" so it should be fixed on the display; also with the attitude centered display a lot of the display is occupied by sky which isn't of much interest

* With VC the gull wing still indicates pitch but the problem is that it is very possible for it to go off screen so lose pitch indication - some didn't seem concerned about pitch indication, but others did.

* The even more significant observation about VC is that it is not conformal with the outside world, so could not be used on a HUD. To see this, note that the velocity vector or flight path symbol appears in the center of the screen (which is fixed to the body of the aircraft) even when there is a crab angle due to a cross wind; thus if landing, the runway symbol would appear under the velocity vector (i.e. in the center) but the out the window real world runway will be off to one side. Another way to look at this is that the pilots body in a crosswind is not facing in the direction that the aircraft is going, so the real world runway appears to one side or the other if the pilot is looking straight ahead out the nose of the aircraft (Note that because the HUD is body-fixed the nose of the aircraft aligns laterally with the center of the HUD. Interesting side thought is what about helmet mounted display (HMD). Is the HMD drawn centered on the pilot line of sight (?) since neither velocity vector or nose of aircraft lie in a constant position on a "conformal display" HMD as the pilot turns his head)

Raw Deviation Pointers

* Standard needle and pointer at bottom and right - these are identical to standard EFIS symbology for raw localizer and glideslope deviation; except numeric deviation is displayed at appropriate end when deviation is pegged

* Dotted square around flight path symbol (which banks with aircraft). This was criticized as redundant with needle and pointer and cluttering up middle. Alternate view was that peripheral needle and pointer were too far out to attract pilots notice and that center type indication was good.

* It was decided to delete the "ILS box" to cut down clutter since it duplicated the raw deviation pointer information - later this was put back when the aircraft was outside the tunnel??

CERTIFICATION

FAA/Certification Comments:

* Mike Norman - some concern about technology readiness/risk of tunnel/pathway concept

* (ref the flashing circle on the ghost aircraft tail) "..you never have continuously flashing things on a display. This is FAA party line. (Berk Greene (B.G.);FAA)"

* B.G.: - don't see risk in certifying tunnel concept; need to consider avionics and aircraft malfunctions; not entirely sold on benefit of tunnel on straight in final (George Lyddane (G.L.)agreed), clearly useful for complex SIDS and STARS - maybe useful for go-around though. Skepticism about whether data link of paths/changes will be reality by 2005(G.L. agreed)- FANS committee working standardized data link messages(?) has thrown up their hands and quit, pilots like long finals and readily abandon FMS when changes occur.

* G.L. - waypoint integrity will not be entirely in the data base; critical waypoints will be data linked up with cyclic redundancy codes, etc. and compared with what is stored in data base - called this the "golden double - key" approach (coming out of Special CATegory, SCAT, committee stuff). Strong lesson from HUD work is that flight path vector (FPV) is very helpful/good, safety increases but A/C is already "safe enough" so must show economic benefit.

* FAA personnel in general seemed to want to see more aspects of the Flight Dynamics symbology - in particular numeric radio altitude just under the flight path symbol; also radio altitude as soon as valid (up to 1500 ft), not just from 500-300 feet down; also if gull wing lies in same location as flight path vector, flight path vector will mask it behind the circular portion; FAA also wanted a solid, white horizon line which NASA had removed in their simulation.

* Radio altitude on latest HUD comes in as soon as it is valid and is displayed underneath the FPV. The FAA likes this "real sensor" (real altitude above terrain??)

MISCELLANEOUS

ATC/FMS:

* Dave Hooper (American Airlines pilot) - takeoff out of Orange County is very steep for noise abatement reasons - pathway with speed management would help.

* Charlie Hynes (Ames) - decelerating approach is another way to cut noise and automatics can handle this okay.

Display Appearance/Symbology Ideas:

* Navigation display inset on NASA's HDD was very effective in showing a plan view of the entire flight path or tunnel; whereas the perspective presentation only shows the portion in front of you. The perspective cone (or wedge in 2D) was shown on the plan view to tie the two together.

* There was a desire to have some way of handling recovery from unusual attitudes; e.g. the chevrons on an ADI at very high pitch angles

* Wind arrow and DME were desired - a "billboard" approach to DME indication was tried.

* Need consistent symbology over entire flight regime (T. Abbott, LaRC)

* At high altitudes (e.g. 65K feet) the true horizon and zero pitch do not line up physically. NASA's simulation biases the top of the terrain to be zero pitch in all cases.

* Some examples of display of alternate paths, i.e. active and proposed alternative, were shown - the examples were fairly rough

* Concern about proper choice of color/hue/saturation/coding, etc.

* Concern about occlusion/interference of symbols, may need priority/"no draw" zones around say FPV

* Runway outline a la HUD - I asked about this. B.G. said history of this was to give some sense of ground awareness, i.e. impending earth {- suggested by Gordon Hardy(Ames)}, they go away at 50 ft because it is important to break fixation; they may also obscure runway edge lights (this was more of a simulator issue, because in the real world they never line up); many reasons why they don't quite line up with real world runway - heading errors are one.

* TV image on HSCT will be color high definition TV because many of real world facility cues are color coded (Mike Norman, Douglas)

* Keep worrying about clutter, particularly when include video or sensor underlays.

* Gull wing (or waterline symbol) is a clutter issue on aircraft that fly near zero angle of attack (with zero AOA, the gull wing overlays the flight path vector) - discussion of this was inconclusive.

Takeoff/Rollout:

* Concern about takeoff and needing some monitor/status maybe along the lines of LaRC Takeoff Performance Monitor System (TOPMS); - human factors of TOPMS symbology was criticized. There were also liability concerns.

Miscellaneous Notes:

* Berk Greene (FAA) wanted aircraft model to account for potential of tail strike - he seemed particularly concerned about this.

* Some concern was expressed that none of the cases flown involved turbulence and lead terms can generate very active control in turbulence

* B.G. did not think panel space in HSR drawing shown was large enough; he thought it was smaller than today's 737 when cutouts for side visibility were taken into account - He was impressed with VISTAS panoramic display

* Control column versus sidestick controller: Boeing position is that the control column is a display device as well as a control element

* There was a request to put up more TCAS targets in simulation - don't know what conclusion/results of this were.

<u>Notes on Pathway Displays Workshop #2</u>
High - Speed Research Program
NASA - Ames Research Center
Hi Russ,

This is a lame attempt to respond to your request for comments on the workshop. Most of my concerns were raised in Mike Johnson's comments and the memo Dave Regal sent out prior to the workshop. I think the workshop itself is a useful forum for rapid prototyping development. Whereas rapid prototyping has its place in design development, it does suffer from a syndrome of too many cooks throwing whatever looks good into the pot. As I mentioned at the meeting, it's my hope that someone will go back and do a "reality check" on the ideas generated at the workshop, and perform systematic evaluation on the best candidates generated.

Some particular issues that stuck with me were:

1) Providing a systematic and consistent use of color coding.

2) Making a meaningful distinction of pathway objects "in the world" and "tied to the aircraft." Objects "in the world" should have canonical geometric properties (e.g., expansion).

3) Dealing with the clutter that results as everyone attempts to place "critical information" near the flight path vector. Some ideas to aid in decluttering were discussed (color coding, "no draw" zones, transparency), but each technique has advantages and drawbacks that need to be considered (e.g., see M. Johnson's comments on transparency). It might also help if pathway objects in this area were "in the world" to ameliorate "HUD fixation." You might want to talk with Dave Foyle about this issue. I think the overall response to pathway concepts was quite favorable (although some of the enthusiasm may reflect a "something is better than nothing bias"). The desire to extend pathways to non-CGI displays demonstrates this, but also raises new issues concerning visibility of non-pathway objects (e.g., runway incursions) via sensor/video imagery. Thus, the issue of clutter remains crucial. I'll be interesting in seeing Mike's notes. Thanks again for an interesting workshop.

Mary Kaiser 10/3/94 5:12 PM

Notes on Pathway Displays Workshop #2

I think that you are on a very good track now with the Pathway display and I am quite pleased with the symbology that is formulating.

I still have some concerns about the loss of real time meteorological visual cues.

I also feel that the present TCAS symbology will lead to excessive clutter in its present form when we display 15 or 20 targets. We will display this many targets in terminal areas like ORD or JFK.

Also, while others talk about removing the pathway while at altitude, I would like to suggest that the pathway be a full time display. This would be the FIRST visual indication that the aircraft were deviating from one or more of it's 4 dimensional values.

Talking about and flying simulations is probably the best way to resolve these and many other issues concerning the development of the HSCT. I do hope that NASA will continue to provide additional workshops. I remain willing and able to participate in any additional workshops. Thanks for your time and dedication to this project.

Sincerely, Dave Hooper

Notes on Pathway Displays Workshop #2

Dear Russ,

I just had an opportunity to visit with Paul Leckman during one of my trips with American. Paul showed me a video that was very impressive. It was a tape of an approach to Aspen. In the foreground was some type of HUD symbology, which could be replaced by the Langley HSCT symbology set. The background was a color rendition of the actual topography. This was the best thing I have seen yet. You could actually fly into any canyon you desired. This depiction was displayed on the PFD. The ND also had an overhead view of the land that was also color coordinated to elevation. You could use this display to see if a particular canyon was or was not a boxed canyon. The flight path vector indicator becomes very important with this type of display. Just place the flight path vector on or above the ridge line and you are clear of the terrain. Tthe forward visibility on the HSCT is going to be reduced. I would like to have this loss of foreword visibility replaced with a visual display of what I would normally see in the real world. Even if it is synthetic. I know that you said that Terry would be hosting any additional workshops, but I just wanted to let you know what Paul has shown me. I think that combining the Langley HSCT symbology set, with this colored display of the topography would be what I would expect to see on an aircraft which is scheduled to fly in 2004. Thanks for listening to me again.

Sincerely,
Dave Hooper - Captain

Technical Highlight:

The second Interactive Workshop on Pathway Displays was held at Langley on Sept. 20 - 22. Ten pilots and fifteen display design researchers participated, with representatives from the FAA, American Airlines, Boeing, Honeywell, Hughes, McDonnell Douglas, Rockwell, USAir, and the NASA. The workshop employed a rapidly reprogrammable pilot workstation that allowed participating pilots to fly pathway concepts and to have all participants make suggestions which were implemented iteratively to arrive at a better understanding of pathway displays. Pathway concepts were enthusiastically and unanimously endorsed by the workshop participants as being extremely valuable for complex approach path "look-ahead" functions and for other situation awareness enhancements, even on "straight-in" approach paths.

Workshop #3
March 21-22, 1995

The Flight Test Symbology Workshop #3

Summary:
The High Speed Research (HSR) Flight Deck Integrated Display Symbology Team, with representatives from D&I, G&C, and XVS, held a Flight Test Symbology Workshop on March 21 and 22, 1995. The workshop objectives were to examine and resolve the symbology issues associated with the pilot-in-the-loop flight operations portion of the FY '95 flight test. The surface operations portion of the flight test will be extremely limited because of the lack of full aft deck steering and braking control. The team determined the symbology set to be used and selected the factors to be examined in the flight test. Of particular significance was the development of a possible control/display mode change procedure for the flare portion of a landing approach intended to provide improved control from the Aft Flight Deck of the 737 during touchdown. Further refinement of the algorithms involved and the procedure itself are necessary. Some other issues remain to be addressed outside of a workshop environment, including symbol color selection against FLIR/color TV background images, fine tuning of a guidance symbology parameter (follow-me aircraft lead-time), determination of a symbol positioning algorithm (follow-me aircraft positioning within a sensor image FOV), and blocking of the experimental conditions across the subject pilots.

Team Attendees:
Terry Abbott
Andy Durbin
Gordon Hardy (Jeff Schroeder)
Walt Johnson (Mary Kaiser)
Russ Parrish

Other Attendees:
Dale Dunford
Linda Foernsler
Randy Harris
Jim Robertson
Steve Williams
Lee Person

PATHWAY WORKSHOP #3 NASA Langley

- 737 AIRPLANE SIMULATION
  - High Fidelity, Central Simulation Facility Tie-in
  - Velocity Control Wheel Steering Mode

- IMAGING SENSORS
  - 1.5 - 5 micron FLIR
    - Radome Mounted
    - 30°H x 22.5°V FOV
  - 8 - 12 micron FLIR
    - Radome Mounted
    - 24°H x 22.5°V FOV

- IMAGING SENSORS (continued)
  - Color Low-Resolution Television
    - Radome Mounted
    - 30°H x 22.5°V FOV, 6x Zoom
  - Color Low-Resolution Television
    - Nose Mounted
    - 81°H x 64°V FOV (minified)
  - Color Low-Resolution Television
    - Fin Mounted
    - 52°H x 42°V FOV (minified)

- DISPLAYS
  - Head-down EFIS PFD
  - Head-down EFIS ND
  - Head-up Image Display

- SYMBOLOGY ELEMENTS
  - Minimal Set
  - PFD Set
  - Follow-me Airplane
  - Pathway
  - Wireframe Terrain Database
  - CGI Terrain Database

OBJECTIVES

- SELECT MINIMUM SYMBOLOGY SET FOR FLIGHT TEST
- SELECT FULL SYMBOLOGY SET FOR FLIGHT TEST
- SELECT FACTORS FOR FLIGHT TEST EXPERIMENT
  - Image: MW FLIR, LW FLIR, TV
    (Surface Ops - above & Fin, Nose)
  - Symbology: Minimum vs. Full
  - Follow-Me Aircraft: Off vs. On
  - Pathway: Off vs. On
  - Wireframe: Off vs. On
  - Image vs. CGI Terrain Database

Detailed Minutes:
The workshop utilized the simulation capability assembled by an XVS team lead by Randy Harris and Steve Williams. Their efforts merged the image generation facilities of the VISTAS/Silicon Graphics Computers with the LaRC central simulation facility's high fidelity 737 aircraft simulation. The resulting capability gave a fairly realistic representation of the aircraft environment that will be used in the FY '95 flight test.

SGI Reality 2 computers were used to provide head-down EFIS displays (PFD and Nav) to VISTAS and to produce simulations of the available imaging sensors at the aircraft locations shown in the table below:

feet	*X* *+ in front c.g.* *- behind c.g.*	*Y* *+ pilot's right* *- pilot's left*	*Z* *+ above c.g.* *- below c.g.*	*ELEV ANGLE* *- down*	*FOV*
PILOT EYE	15.94	2.53	4.27		
Monitor Center	18.77	2.53	4.40		30°H x 22.5°V
MW FLIR	37.32	-0.23	-4.00	-8°	30°H x 22.5°V
LW FLIR	37.32	0.23	-4.00	-8°	24°H x 22.5°V
Color CCD	37.32	-0.23	-4.27	-8°	30°H x 22.5°V
Nose Camera	41.46	0.00	-1.91	-5°	81°H x 64.2°V
Tail Fin Camera	-41.61	0.00	27.71	-30°	52.4°H x 42V°

Sensor image output was fed via NTSC video to an SGI VGX computer (two generations older than Reality 2) with identical capabilities to the on-board ATOPS SkyWriter. The VGX digitized the sensor image and combined the image with the appropriate symbology set. The VGX computer also produced the symbology set, the pathway, the follow-me aircraft, a wireframe terrain database, and a filled polygon CGI terrain database, as selected.

The symbology issues and options addressed were limited to the approach and landing task with the firmware restrictions imposed by the flight test sensors and equipment. As such, integration issues relating to other flight deck displays (e.g., the PFD) were not discussed.

There will be a single scenario used of the symbology evaluation part of the flight test. This will consist of an initial flight segment 90-degrees to the approach path with a single turn to a short final approach segment for landing. A key quantitative factor for the display evaluation will be touchdown dispersion. This is significant in that Lee Person does not believe that the current ATOPS control-display implementation will support this requirement. A possible solution for this was discussed and is provided below.

The initial symbology set that was used as a starting point for this work was based on the display format selected at the last Pathway Workshop at LaRC. Major modifications to that baseline for the sensor flight test are as follows:

1. A flare cue was added and will be used with all symbology combinations. A magenta line will appear at the bottom of the FOV at 100 feet(?) and rise proportional to altitude changes to meet the -3° pitch/flight-path reference at 50 feet (?), where it will continue to rise and present the flare cue via an hdot/h flare law.
2. A pitch/flight-path reference symbol for a 3-degree approach angle will be provided whenever a precision approach path is not provided.
3. It was found that (for most of the flight conditions) driving the velocity-vector with actual gamma introduced high pilot workload for the guidance tracking task. In general, commanded gamma will be used to drive the velocity-vector symbol. This is the same approach used in the ATOPS.
3. In an attempt to augment the touchdown performance with the current ATOPS control-display implementation, a transition from commanded gamma / to actual gamma will be used during flare and touchdown, with the velocity-vector being fully driven by actual gamma at touchdown.
4. In addition to item 3, we are considering using attitude-control-stick-steering (ACSS), as opposed to velocity-control-stick-steering (VCSS), during the final part of the landing task. This concept will require further evaluation. In addition, to support this control mode switching, the ATOPS simulation and flight software will need to be modified to provide a gamma command value when in ACSS.
5. The color for the FLIR sensor image does not provide sufficient visual contrast with the majority of the symbology. This needs to be resolved.

Two major symbology sets were developed. The first set (set 1) would conceptually be used for a visual approach task where there is no pre-defined flight path. The second set would be used with a pre-defined path. For this latter situation, two symbology sets were defined. Set 2b would provide all path guidance and path symbology. Set 2a is a subset of set 2b, but the 3-D pathway will not be shown (this is a 'decluttered' mode). The symbology sets are provided in the following table.

Set definitions:
Set 1 is no pre-defined path, similar to visual approach requirements.
Sets 2a & 2b are for a pre-defined path, similar to a precision approach.
Set 2b is a "decluttered" subset of 2a. No 3-D pathway is displayed.

SYMBOLOGY	SET 1	SET 2a	SET 2b
attitude scale (pitch grid)	X	X	X
attitude "waterline"	X	X	X
roll scale & pointer	X	X	X
airspeed & altitude tapes(see note)	X	X	X
velocity-vector	X	X	X
vertical speed	X	X	X
absolute altitude	X	X	X
control panel altitude target on altitude tape	X	X	X
control panel speed target on speed tape	X	X	X

speed trend on speed tape	X	X	X
speed error on v-v symbol	X	X	X
potential gamma relative to v-v symbol	X	X	X
track angle & heading	X	X	X
flare cue	X	X	X
reference marker for flight-path (pitch) angle	X		
lateral & vertical path error scales and pointers		X	X
path altitude target on altitude tape		X	X
path speed target on speed tape		X	X
guidance "follow-me" symbol		X	X
pathway			X

note: Only tapes will be used for the flight test. The issue of tapes or digital-only are not a primary factor for this study and therefore were not included.

The test matrix defining the combinations of background images and symbology sets is given below. Note that all combinations may not be flown by all pilots. Also note that the wireframe subset is the DMA database ground environment outline used for navigation source/sensor alignment evaluation.

Background Image		Symbology set		
		Set 1	Set 2a	Set 2b
FLIR	w/o wireframe	X	X	X
	with wireframe	X	X	X
TV	w/o wireframe	X	X	X
	with wireframe	X	X	X
CGI		X	X	X

Continuing development, problems noted, and action items:

1. The guidance symbology (follow-me aircraft) should track the flare cue once the flare cue becomes the valid command.
2. Contrast between symbology and the FLIR image needs to be resolved. It may also be an issue with actual color TV video.
3. The algorithm for the velocity-vector symbol during final approach, flare, and touchdown needs further refinement and evaluation.
4. ACSS needs further evaluation and possible modification.
5. Gamma command information needs to be computed for ACSS conditions.
6. The flare cue did not function correctly for all of the proposed sensor look-angles.
7. The attitude 'waterline' symbol was embedded in the roll scale for some of the proposed sensor look-angles.
8. The rudder pedals need to be operational.
9. The lipstick cameras (tail fin and nose) need to be minified.

10. The follow-me aircraft lead time needs to be tuned. It is presently set at 8 seconds (tuned for a generic transport model), and it may be desirable to vary the time parameter as a function of range.
11. The algorithm for the positioning of the follow-me aircraft needs to be determined for each sensor image FOV.

ACWS Tuning Investigation

Of particular significance during the Flight Test Symbology Workshop on March 21 and 22, 1995 was the development of a possible control/display mode change procedure for the flare portion of a landing approach intended to provide improved control from the Aft Flight Deck of the 737 during touchdown. The following was extracted from the minutes of the workshop.

It was found that (for most of the flight conditions) driving the velocity-vector with actual gamma introduced high pilot workload for the guidance tracking task. It was decided that in general, commanded gamma will be used to drive the velocity-vector symbol. This is the same approach used in the current velocity-centered ATOPS displays. In an attempt to augment the touchdown performance with the current ATOPS control-display implementation, a transition from commanded gamma / to actual gamma was proposed to be used during flare and touchdown, with the velocity-vector being fully driven by actual gamma at touchdown. In addition, we are considering using attitude-control-stick-steering (ACSS), as opposed to velocity-control-stick-steering (VCSS), during the final part of the landing task. This concept will require further evaluation. In addition, to support this control mode switching, the ATOPS simulation and flight software will need to be modified to provide a gamma command value when in ACSS.

On April 27, 1995, I invited the following to VISTAS Lab:

Rob Rivers, LaRC test pilot
Lee Person, retired LaRC test pilot
Dave Raney, GCB control systems engineer
Bill Lynn, ATOPS control systems engineer
Steve Williams, CVIB graphics programmer
Patricia Hunt, Lockheed graphics programmer

The purpose of the meeting was to look at the flare and touchdown characteristics of the ATOPS aircraft control system that will be used for the sensor flight tests conducted in September, 1995. Consensus was arrived at in the following areas:

(1) It would be impractical and unnecessary to tune the aircraft attitude control wheel steering mode before the flight tests, as there would not be enough time available in the airplane to do it.
(2) For the landing tests the control system should be left in velocity control wheel steering mode; that mode, with the new flare symbology immplementation on the Skywriter displays, should provide acceptable touchdown performance from the aft deck.

(3) The display symbology should be modified so that if there is an error between commanded gamma and actual gamma of more than 0.5 degrees for more than 1 second, a dotted flight path symbol would be drawn representing the actual flight path.
(4) VISTAS sidearm controller characteristics in the roll axis make piloted studies of precise lateral control very questionable. The deadbands in the lateral axis of the sidearm controller are too large. A new sidearm controller is needed.
(5) Use quickened flight path angle when flying in attitude control wheel steering mode. and
(6) The sensor display with symbology is much easier to fly than VFR flight, even at 12 hertz update rate. There should be no problem flaring the airplane with that display and the flare symbology.

The following improvements could be make to the simulation:
(1) Display commanded track angle and actual track angle.
(2) Use the two buttons on the top of the VISTAS sidearm controller to slew the commanded track angle (this capability is present in the aft deck with the coolie hat trim button). This implementation would overcome the VISTAS sidearm controller problems in the roll axis
(3) The range to the ghost aircraft seems to be too small.
(4) Three degree reference line should be separately selectable

Therefore, no additional tests are needed to tune the ATOPS attitude control wheel steering for the sensor flight tests.

Randall L. Harris, Sr.
46641

Date: 4/28/95 1:57 PM
To: Randy Harris
From: Terence Abbott
Randy,

I thought that the most significant thing that came out of the previous workshop regarding landing the 737 from the AFD was the blending from commanded to actual gamma to drive the flight path symbol during the landing flare. THIS IS INDEPENDENT OF CONTROL MODES. I also believe that the 1/2 of degree over a 1 second period will continue to mask commanded/actual gamma differences, primarily because the landing flare maneuver is a short-term, highly-dynamic (for a transport) maneuver. The biggest problem in the longitudinal axis in landing the 737 is that the control & display system in the AFD is open-loop in the short-term. You cannot really see what the aircraft is doing. I have very great reservations reverting to this approach.

Terry

Terry,
Both pilots felt this was the better way to go. They did say that if we decided to go the other way we should use quickened gamma and not raw gamma. The problem with raw gamma is that it moves the wrong direction first before going the correct way (quote from Lee).
Terry : (I thought that from the previous workshop that a blend from commanded to actual gamma would be used to drive the flight path symbol during the landing flare. Your consensus item #3 uses a different approach that except for your recent meeting, has not been able to produce consistent landing results. Why was this changed from the previous implementation?)

You had to be there (I felt Lee made a reversal of the things he said previously. Both Rivers and Person felt that it would be impractical to switch from VCWS to ACWS. Therefore, it made more sense to display only the commanded gamma if you would display actual gamma when there was a difference of more than 1/2 degree.

Terry : (- From your consensus item #5, if we will not transition to ACSS during the landing, why should we even consider ACSS? It looks to me like we'll be using VCSS throughout the test (based on your items #1 & #2).)

That is correct. For these tests we will not be using ACWS.

Terry : (- I question your consensus item #6 result. How were you able to obtain a VMC landing touchdown comparison?)

These statements in #6 were the opinion of both pilots, Rivers and Person. Lee made the comment comparing it to VFR because of the symbology (more precise information) present in the display and because of the larger magnification factor of the display over the EADI (velocity-centered) in the ATOPS. Both pilots were able to make touchdowns in the VISTAS simulator that were below 3 fps when the throttles were not retarded before TD.

I am sorry you could not have been there. We will readdress the problem when Mike Norman is here with Rob Rivers on May 25.
Randy

Primary Flight Display (PFD) Symbology Description

Flight Deck Integrated Display Symbology Team

Primary Flight Display (PFD) Symbology Description

edited by Terence Abbott
7 July 1996

The intent of this informal report is to document the preliminary XVS/PFD symbology set developed primarily by the XVS flight test team for the XVS sensor flight test experiments. The development of this symbology took place over a two year period and included several symbology workshops that provided for interactive symbology development during the workshop sessions. This report will attempt to describe the symbology, the symbology 'drivers' or algorithms, and any significant or unique issues that were identified. As a caveat, the symbology set described in this report was developed to support the XVS sensor flight test and other similar XVS studies. As such, this symbology has not been rigorously evaluated in either full-mission or full-workload scenarios.

Figure 1 has been provided by XVS. The subsequent figures are modifications of the original and include numbering of the symbology elements that will be used later in the text to describe the symbology.

Abbreviations and Definitions

FPG:	Flight path guidance, ghost aircraft, phantom aircraft.
FPM:	Feet per minute.
FPV:	Flight path vector, velocity vector.
RA:	TCAS resolution advisory.
Crosshairs:	Two cue flight director.
Ownship:	Your aircraft.

Symbology Elements

The general references for this section are SAE ARP4102/7 and numerous, informal notes provided by the XVS team. The numbers of the numbered paragraphs related to the numbered items on the figures. Footnotes are provided on the last page that identify the source of the various comments.

1. Flight Mode Annunciator (FMA): Flight guidance and flight control modes should be clearly annunciated. It is also recommended that all guidance and control mode annunciation symbology be grouped together. (For further information, contact Michael T. Palmer, NASA-LaRC.)

2. Roll scale: As a minimum, tic marks should be provided at 0°, 10°, 20°, 30°, 45°, and 60°. The 45° and 60° may be programmed to appear at angles greater that 30°. Digits are not required. The 30° mark should be distinct.

3. Roll pointer: The roll pointer should have priority over all other symbology. A slip (lateral acceleration) indicator symbol should augment the roll pointer symbol.

Figure 1.

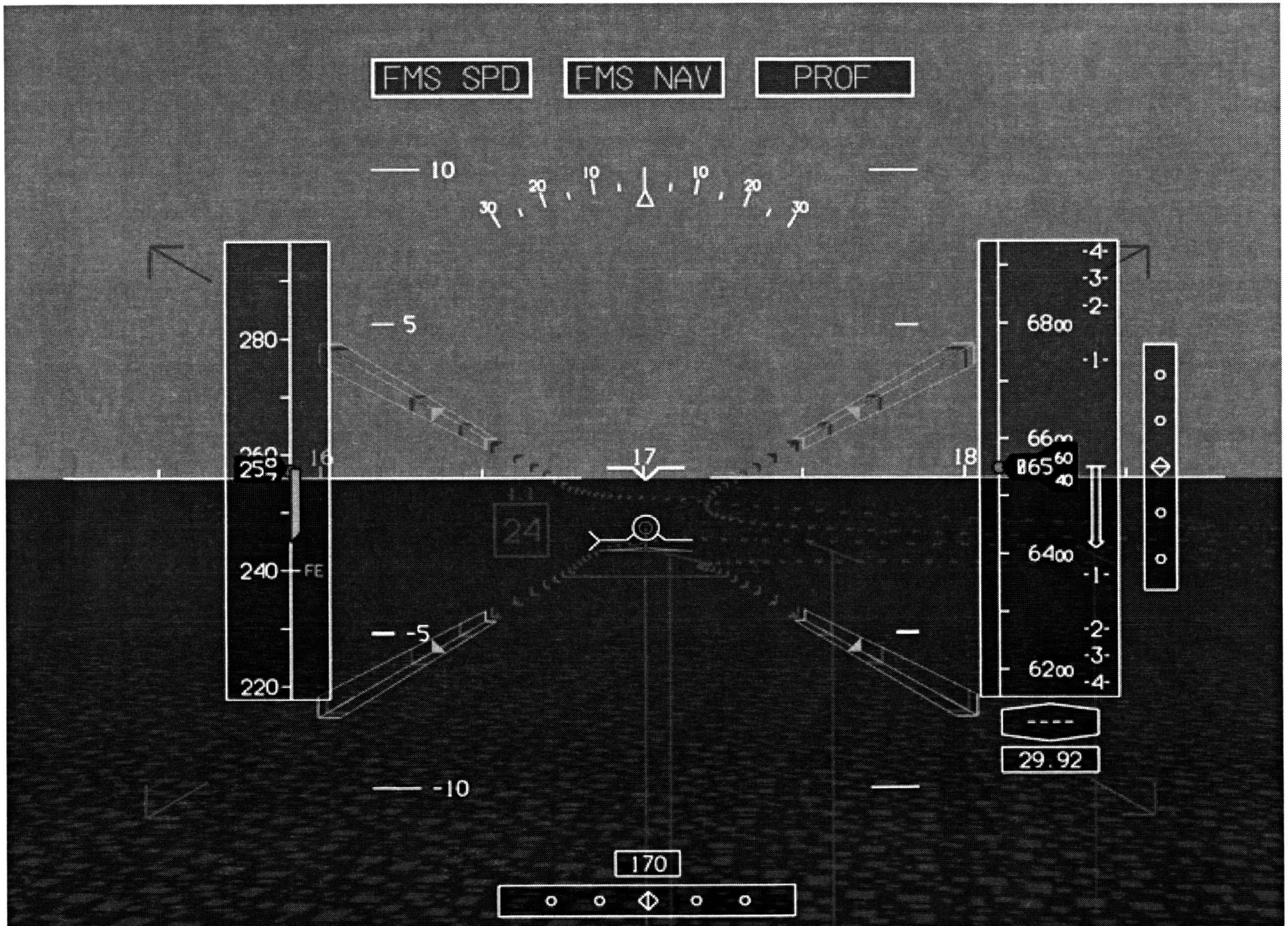
FMS SPD
FMS NAV
PROF
10
5
-5
-10
280
260
240
220
FE
16
17
18
6800
6600
6400
6200
60
40
29.92
170
24

Figure 2a.

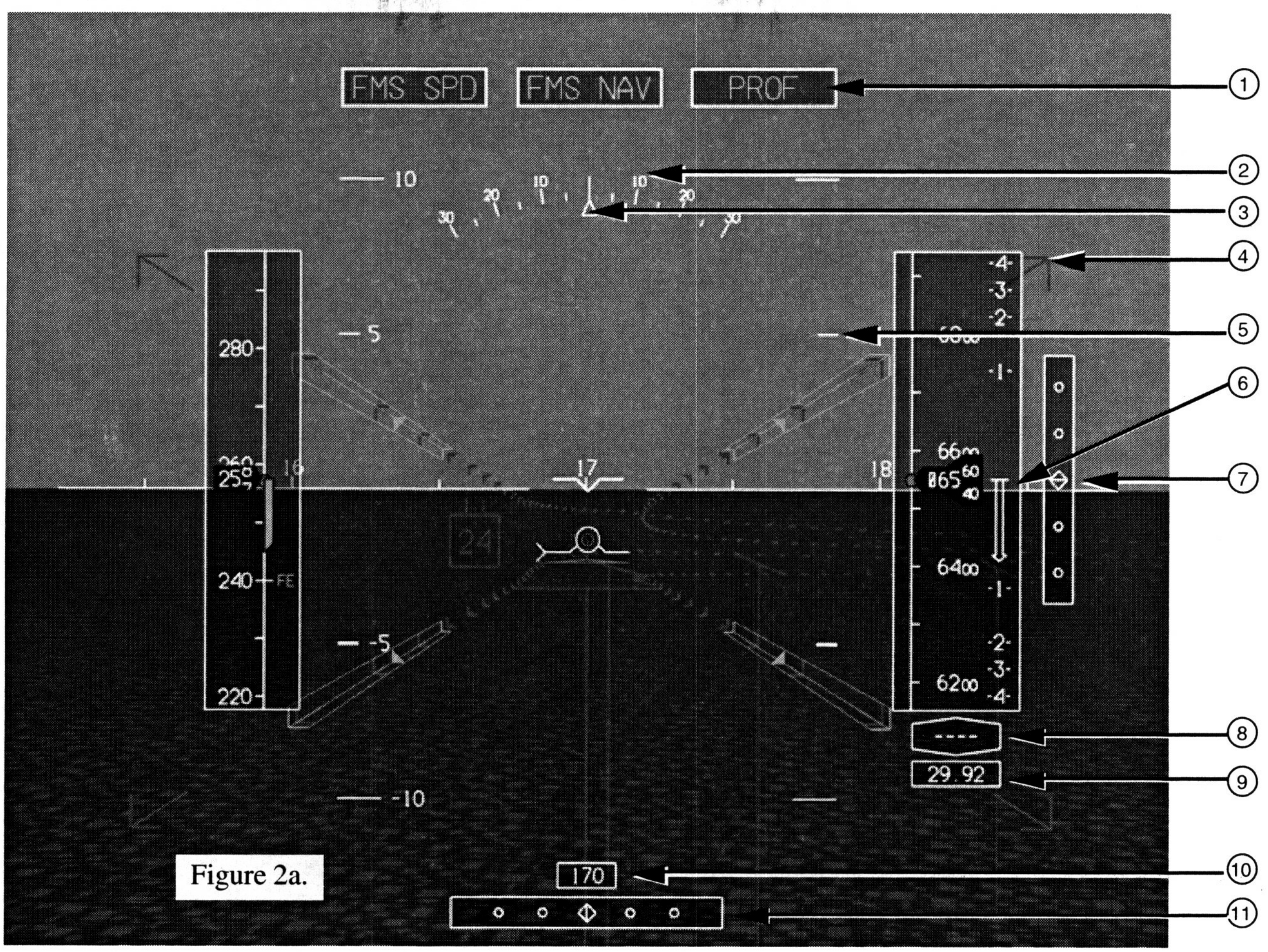

Figure 2a.

4. 3-D pathway symbol:

- Several initial types of flight path "tunnels" were reviewed. The Dorighi Tunnel is defined by four dotted lines at the edge of an acceptable error box, with square guidance symbols inside the dotted lines, and a reference solid box at a fixed time reference ahead of the aircraft. The "Noodle Tunnel" is defined by a series of boxes, leading from the present aircraft position to a reference position on the cleared path, or final approach fix. The NASA Langley Goal Post Tunnel is defined by partial boxes consisting of side and bottom segments, center pillars extending from the bottom of the boxes to the terrain floor, and rectangular tiles inside the boxes defining the path to be flown. [1]
- After an initial evaluation by all of the pilots present, the consensus was that the "Noodle Tunnel" had little for the HSCT application and was not evaluated further. The rationale for this decision was that because the beginning of the tunnel was always tied, laterally and vertically, to ownship

position, this tunnel provided no cues to path error, merely showing a route back to the desired path. [1]

- A discussion occurred on whether to provide a pathway display element during constant heading flight modes or during cruise modes in general. This evolved into a discussion, again, on what constitutes a pathway. The consensus among the group was that a pathway is a defined three dimensional line in space, consisting of curved and/or straight segments, over fixed earth-referenced coordinates. Pathways could also have a time critical dimension associated with them, during 4-D clearances. This definition is consistent with what is presented on FMS map displays in current aircraft. Constant heading modes may not fit this definition. It was suggested that pathways not routinely be displayed in constant heading modes due to difficulties in display or interpretation of lateral flight path errors. It was also suggested that pathways, in general, be a pilot selectable display element, so that they could be removed in situations where they would be confusing or clutter the display. [1]

Figure 2b.

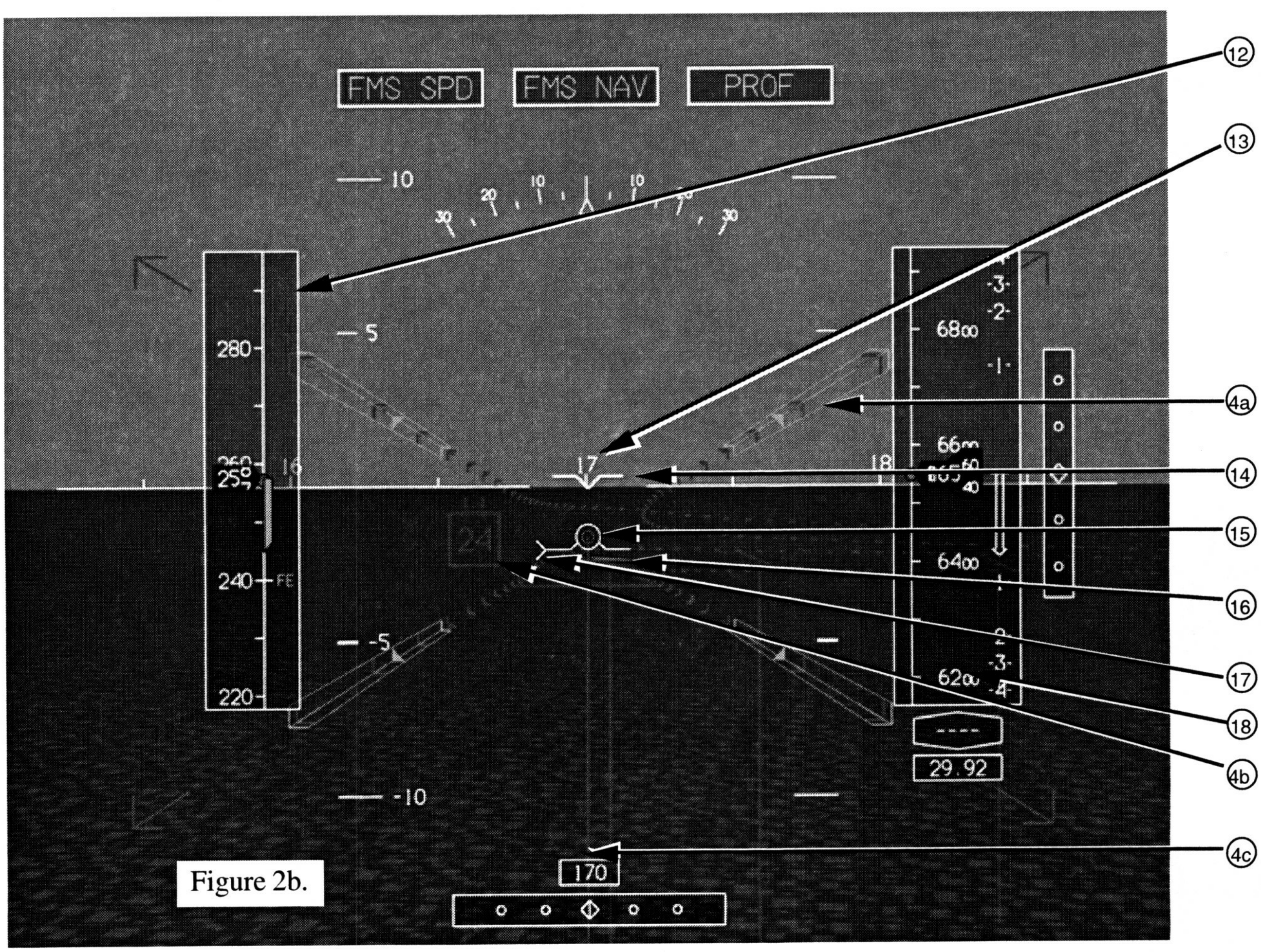

Figure 2b.

- A pathway is not appropriate for all cases; a pathway is "attached to the earth" in normal viewpoint so doesn't work for heading hold, performance climb or descent, etc., which are not tied specifically to the earth although they may have to be accomplished in some volume constraints. [4]
- The issue of how to display a two dimensionally constrained pathway was discussed. This situation could occur, for example, during climb or cruise/climb. In this situation, a cleared route over the ground would exist (a 2-D path), along with an expected altitude at the end of the segment, but no specifically cleared vertical path would exist to get there. It would not be appropriate to display a three dimensional pathway here, since following minor vertical path errors, the pilot would not be expected to return to the previously computed optimum performance path, and a new optimum performance path should continuously be computed. The distinction between path and guidance information should be stressed here - the pathway does not indicate how the pilot should reduce path errors (guidance cues do that), it merely displays those errors. It was suggested that when pathways are laterally, but not vertically constrained, the displayed vertical error should be zeroed at all times. The pilot, then, could fly laterally off the path, but never above or below it. The practicality or usability of this display philosophy remains to be demonstrated. [1]
- There may be a need, in presenting pathways, of distinguishing cleared flight paths from expected flight paths. [1]
- The need to show missed approach information was discussed. During approaches, the pilot will need this information both to help plan for flight path requirements and to visualize the projected flight path with respect to terrain, other waypoints, airport references, etc., in the event of a missed approach. [1]
- The need for color standardization in display elements was discussed. Cleared flight paths, for example, are traditionally displayed in magenta on FMS map displays, and should probably be displayed in that color on pictorial displays. Proposed or alternate flight paths could be displayed in white, color intensity, dotted lines, or suppressed resolution to distinguish them as planned paths, on pictorial displays. [1]
- The problem of indicating cleared versus planned altitudes was mentioned. For example, a descent route segment may begin at Flight Level 350 and end at 5000 feet MSL, but the aircraft is only presently cleared 15,000 feet MSL. One method suggested of indicating this in path data was to present a pseudo cloud deck, or translucent tiles, at the cleared altitude on the display. Further study is warranted to arrive at an acceptable method of display. [1]
- It was generally agreed that the edges of the tunnel should correspond to the required error tolerance in flight path control. Some method for discerning desired error tolerance should also be provided. [1]

4a. Precision 4-D 'time rail' symbol: Only needed for 4-D path control.

- The display of four dimensional pathways (those which include time constraints) will probably require both status and guidance display elements relating temporal errors. Two predominate philosophies exist relating to time constraint guidance - speed control and volume clearance. Further study is warranted to develop appropriate cues for four dimensional status and guidance display elements. Of note, these may be difficult when the desired clearance volume is behind the aircraft. [1]
- Angle irons on the front portion of the tunnel are used to show the status of the time requirement. The symbol represents a 4 second interval; the small right-angle pointer in middle indicates exactly on time. The symbol is normally amber with the right-angle in green; the symbol turns yellow if the right-angle pointer leaves the symbol but is between 4 and 6 seconds off and turns red if pointer is more than 6 seconds off. [4]
- The right-angle pointer symbol limits for being ahead-of-time, but drops behind the angle irons for being behind-time. A suggested modification was to limit the pointer symbol in both directions and to display time error digitally while limited. [4]

4b. Along-path, distance-to-go marker: The number displayed in the 'box' is the distance from the 'goal post' to the runway, in nautical miles. The number above the 'box' is the distance from ownship to the 'goal post.' In this example, ownship is 25.1 n.mi. (along the planned flight path) to the runway.

4c. Ground reference 'goal post' symbol: The 'goal post' is an augmentation to the 3-D pathway symbology. The 'goal post' is anchored to the ground plane and the horizontal line forming the 'T' is at the bottom of the 3-D path. The length of the vertical portion of the 'goal post' enhances situation awareness regarding the pathway height above the ground plane.

- Several of the pilots objected to the amount of clutter, particularly early in the approach, where numerous goal posts could be seen. [1]
- When the pathway is shown overlaid on a video background, the goal post may project to the nominal geometric plane of a flat earth despite the presence of rough and perhaps mountainous terrain. Adjusting the height of the goal posts so that they intersect the real earth volumes present in the video image may be difficult to do and certainly implies an elevation database or dynamic means of estimating elevation in real time. [3]

5. Pitch scale including horizon line: See SAE ARP4102/7 for a general arrangement. Recent research suggests that the pitch scale should become nonconformal at extreme pitch attitudes such that the horizon line always remains within view. [8]

- There was a desire to have some way of handling recovery from unusual attitudes; e.g. the chevrons on an ADI at very high pitch angles. [4]

- FAA recommended a solid, white horizon line which NASA had removed in their simulation. [4]

6. Instantaneous vertical speed: A 100 FPM resolution is required from 0-1000 FPM. A vertical speed target is desired if vertical speed guidance is provided. TCAS II resolution advisory (RA) symbology should be included.

7. Precision vertical path deviation indicator and scale: The navigation source for this scale must be displayed. The recommended placement is between the attitude symbology and the altitude symbology.

8. Radio height: This symbol (presented in a numeric format) may not be required for invalid radio heights.
   - FAA personnel in general seemed to want to see more aspects of the Flight Dynamics symbology - in particular numeric radio altitude just under the flight path symbol; also radio altitude as soon as it is valid (up to 1500 ft), not just from 500-300 feet down. [4]

9. Baroset readout: "STD" may be used above the transition altitude. The altitude reference (QFE, QNH) and the units (IN, HP) should be annunciated with the baroset readout.

10. Magnetic heading: May not be required for all flight modes. Leading '0' digits are required such that 3 digits are always displayed.

11. Precision lateral path deviation indicator and scale: May not be required for all flight modes.
    - Two types of information should be provided on the forward display - pathway or position error (three or four dimensional), and flight guidance cues. Pathway or position error cues should be easily interpretable, and ideally should provide desired, as well as allowable, tolerances in the display element. Initially, traditional crosshairs were provided around the velocity vector to indicate desired path error limits. Later, these were replaced by a dotted box that was positioned in relation to the velocity vector so as to indicate lateral and vertical path error. The dotted box was preferred over the crosshairs, in that it decluttered the critical area immediately around the FPV, and was more easily interpreted than the crosshairs. Some pilots, however, still wanted analog error scales (similar to ILS raw data indicators) at the edge and bottom of the display. An additional digital display, indicating path error in equivalent "dots", was provided adjacent to the analog scales, which some of the pilots felt was a valuable addition to the display element. Concern was expressed, however, that these scales would interfere with altitude and/or velocity tapes on the display, particularly in high crosswinds. Further study is warranted to reduce the size of the analog scales, and move them to a location where they will not interfere with other display elements. It

was also suggested that the scales and error box should be individually selectable by the pilot. [1]

12. Augmented airspeed tape:
   - In addition to the airspeed information, provided by the moving-tape, precision speed information is provided by the 'rotating-drum' (odometer-type) symbology centered vertically on the airspeed tape. Additional speed related information is provided (similar to MD-11 or B-777) including: airspeed trend (acceleration), stick-shaker speed, Vmin, V1, V2, Vref, maximum configuration (flap retract) speed, minimum configuration (flap extend) speed, ground speed, Vmo, Mmo, and speed reference. The entire set of additional information may not presented (or required) at one time.
   - The recommendation to replace the analog airspeed symbology with a digital-readout continues to be raised throughout all of the workshops. The intent of this replacement is to reduce display clutter on the XVS. Further analysis is required in this regard since a significant amount of information is removed in this replacement.

13. Heading markers on horizon line: This symbology may not be required for all flight modes. This symbology may add to the central "area-of-interest" clutter problem.

14. Aircraft (pitch) symbol reference:
   - If the aircraft attitude symbol lies in same location as flight path vector, the flight path vector will mask it. [4]
   - The attitude 'waterline' symbol may become "embedded" in the roll scale for some of the proposed sensor look-angles. [6]

15. Flight path vector (FPV) symbol:
   - It was found that (for most of the flight conditions) driving the velocity-vector with actual gamma introduced high pilot workload for the guidance tracking task. [6]
   - The display symbology should be such that if there is an error between commanded gamma and actual gamma of more than 0.5 degrees for more than 1 second, a dotted flight path symbol would be drawn representing the actual flight path. [7]

16. Flight path guidance (FPG) (phantom aircraft, pursuit aircraft, ghost aircraft) symbol:
   - Two types of information should be provided on the forward display - pathway or position error (three or four dimensional), and flight guidance cues. The guidance cues should be simple enough that in high workload situations, the pilot is guided quickly on where to position the aircraft attitude and thrust (as applicable). [1]

- Consideration must be given in the design of the guidance cue such that satisfying the cue will not result in any extreme or hazardous flight condition. [8]
- A discussion occurred concerning the difference between guidance and pathway information. It is entirely conceivable that guidance cues may lead the pilot away from the pathway, as in a brief ATC vector off course. One suggested philosophy was that a pathway be displayed when a route segment has been entered or computed in navigational planning systems (as in an FMS route in today's systems). [1]
- One problem with pursuit guidance was discussed, in that during turns, this guidance will lead to flying to the inside of the turn, or cutting the corners. Two solutions to this problem were addressed: deliberately positioning the ghost aircraft to the outside of the turn by a programmed amount, or providing a second order correction to the position of the FPV on the display during turns. The latter method has the advantage of also providing a more accurate prediction of aircraft future position in turns, at the expense of a somewhat more active display cue, unless damping is included. [1]
- Critical guidance symbology, such as the velocity vector or the pursuit aircraft cue, should never be allowed to disappear off the edge of the display. Some method should be provided to indicate the extrapolated position of the cue, as well as the fact that the cue has pegged on the display. Methods which could be used include freezing the cue at the proper position on the display (in a line to the actual position), flashing the cue, changing colors, hiding half or a part of the cue, or dotting the display lines constituting the cue. The method used for this study was to change the cue color to red. [1]
- Initially, the guidance cue changed from the pursuit aircraft to circular flight director cue at 200 ft agl. This change in symbology near to touchdown proved distracting, and the cue appearance was changed so that it remained as a "ghost aircraft" throughout the flare and touchdown. NASA Ames reported successful use of a shadow cue oriented around the ghost aircraft in the flare. We were not successful in this workshop, however, in implementing the shadow cue in any acceptable manner, as attempts resulted in a distracting, cluttered flare cue. [1]
- In a go-around, the "ghost aircraft" would disappear and only raw data would be available. The transition to raw data was abrupt and not desirable. The aircraft guidance logic should be expanded for full-mission. This should also include a readout of the guidance mode which the ghost aircraft is currently operating. Mode examples include approach, go-around, cruise, climb, descent, vertical nav climb/descent, VS, windshear escape, and engine out go-around. The pilot needs to know where the guidance is taking him and why. [2]
- The "guidance" should be consistent for all flight modes. For modes like heading hold/capture, altitude hold/capture, using a ghost aircraft displaced from the FPV to indicate guidance commands will appear to the pilot much like "chasing" the ghost aircraft down the pathway, even though the underlying "guidance algorithms" may be quite different. The area where

there may be an inconsistency at present is when the aircraft is outside the pathway and on an intercept course. With the current algorithm, the ghost aircraft position is based on a perpendicular dropped from the ownship position to the pathway. In some ways this seems quite natural since you watch the ghost fly down the pathway and simply "fall in behind him". However, if you are in a heading hold mode flying an intercept path with respect to the pathway, the ghost should underlie the FPV if you are on the correct heading and it should then provide transition guidance (onto the pathway) at the appropriate point. [3]

- If the ghost aircraft flies down the center of pathway, ownship tends to "cut" the corners. The algorithm has ghost aircraft fly outside of the pathway in turns so that ownship stays in the pathway. An alternate approach would be to have the ghost aircraft stay in the pathway (i.e. not be compensated) and to track it with a "quickened" or acceleration compensated flight path symbol. This approach was not liked as well in a cursory evaluation ("too active"), but the implementation may not have been optimized. This approach may also pose problems when not flying chase or when trying to take crab out on landing. [4]
- Concern was expressed that the ghost aircraft was contributing too much visual clutter when flying the pathway, but was useful when acquiring the pathway. A compromise may be to show the ghost aircraft when outside the pathway and simple circle guidance cue when inside the pathway. [4]
- Lots of "white things" add up in the middle, make the ghost aircraft magenta. [4]
- The guidance symbology should track the flare cue once the flare cue becomes the valid command. [6]
- The algorithm for the positioning of the ghost aircraft needs to be determined for each sensor image FOV. [6]

17. Flight path acceleration symbol: No comments were noted.

18. Augmented altitude tape:
    - In addition to the altitude information, provided by the moving-tape, precision altitude information is provided by the 'rotating-drum' (odometer-type) symbology centered vertically on the altitude tape. Additional altitude related information is provided (similar to MD-11 or B-777) including: radio altitude (analog) symbology, decision height, and altitude references. The entire set of additional information may not presented (or required) at one time.
    - The recommendation to replace the analog altitude symbology with a digital-readout continues to be raised throughout all of the workshops. The intent of this replacement is to reduce display clutter on the XVS. Further analysis is required in this regard since a significant amount of information is removed in this replacement. [8]

Symbology and XVS clutter/interference:

- Competition between symbology and background video: Haloing, using a thin black border encircling all the high priority symbology, is designed to allow for the primary symbols to be easily discerned, regardless of the intensity of the surround. Easy discrimination of symbology will become especially important when the pathway is overlaid on a field of video. Video presents a wide range of intensity and color patterns making a priori color and intensity selections of the pathway symbols difficult to do unless an occlusion method is used. Video, or a reasonable facsimile of it (perhaps photographically texture mapped terrain), is needed in future pathways experiments to adequately assess how the pathway will interact with the primary VMC sensor. There is also a major concern for eliminating or reducing the risk of obscuring objects that might otherwise lie hidden beneath the overlaying symbology. [3]
- The possibility for an additive or translucent method of annunciating the symbology should be explored so as to test for ways of minimizing the obscuration of objects residing beneath symbols. (Experiments that Russ Parrish did in this area some time ago showed that the underlying video and the symbol interfered with each other and both became difficult to "read".) These experiments were informally executed using the "golden eyeball" approach. It may be fruitful to investigate ways of overlaying symbols on sample fields of video using a more controlled and formal procedure. [3]
- One approach raised at this workshop regarding clutter/interference was, "How do HUDs in use today circumvent the problem?" The answer to that question may provide guidance here. [3]
- Note that in using an actual HUD, small head movements largely overcome this blocking issue through the effective use of parallax. [8]
- Concern about occlusion/interference of symbols may require priority "no draw" zones around primary symbology. [4]
- Runway outline a la HUD: History of this was to give some sense of ground awareness, i.e. impending earth. This symbology should be removed at 50 ft altitude because it is important to break fixation. This symbology may also obscure runway edge lights (this was more of a simulator issue, because in the real world they never line up); many reasons why they don't quite line up with real world runway-heading errors are one. [4]
- Aircraft pitch symbol reference is a clutter issue when the aircraft is flying near zero angle of attack (with zero AOA, the gull wing overlays the flight path vector). [4]
- The major issue is dealing with the clutter that results as everyone attempts to place "critical information" near the flight path vector. Some ideas to aid in decluttering were discussed (color coding, "no draw" zones, transparency), but each technique has advantages and drawbacks that need to be considered (e.g., see M. Johnson's comments on transparency). It might also help if pathway objects in this area were "in the world" to ameliorate "HUD

fixation." (Dave Foyle at Ames can provide some insight on this issue.) The overall response to pathway concepts was quite favorable (although some of the enthusiasm may reflect a "something is better than nothing bias"). The desire to extend pathways to non-CGI displays demonstrates this, but also raises new issues concerning visibility of non-pathway objects (e.g., runway incursions) via sensor/video imagery. Thus, the issue of clutter remains crucial. [5]

Other symbology options:

- Speed error on the flight-path vector symbol: This is a vertical line (implemented but not shown in the example) on the left "wing" of the flight-path vector symbol. The length of the line is proportional to the speed error.

- Roll limit indicator: Shows the current roll limit (g-load maneuver limit). See the MD-11 documentation for an example of this symbol.

- Flare cue: A magenta line that appears at the bottom of the FOV at 100 feet (during landing) and rises proportional to altitude changes to meet the -3° pitch/flight-path reference at 50 feet. It will continue to rise and present the flare cue via an hdot/h flare law. [6]
- Pitch/flight-path reference symbol: A pitch/flight-path reference symbol for a 3-degree approach angle is provided whenever a precision approach path is not provided. [6]

General symbology notes:

- Meaning of pathway walls: What is the consequence of going outside the pathway - sometimes the meaning is trivial, but if the pathway is to avoid terrain, going outside could be catastrophic. On final approach, tying the pathway to the emerging "tunnel" certification criteria seems logical but further-out (from the airport) and enroute things are less clear. Flight corridors, e.g. across Atlantic, are set wide to account for navigation errors. [4]
- The pathway width should reflect what the pilot should stay within so that the sum of the path following errors and the navigation imprecision keeps the aircraft in the required corridor. [4]
- A meaningful distinction of pathway objects "in the world" and "tied to the aircraft" must be made. Objects "in the world" should have canonical geometric properties (e.g., expansion). [5]

[1] From: Pathway Workshop Discussion Items, April 25-27, 1994.
[2] From: Dave Hooper's Suggestions, September 9, 1994.
[3] From: 2nd Interactive Workshop on Pathway Displays, September 1994.
[4] From: T.G. Sharpe, Notes on Pathway Displays September 1994 Workshop.
[5] From: Mary Kaiser, Notes on Pathway Displays September 1994 Workshop.

[6] From: Flight Test Symbology Workshop, March 21-22, 1995.
[7] From: ACWS Tuning Investigation, April 27, 1995.
[8] Editor's comments.

Workshop # 4

September 4 - 5, 1996

Invitation to Workshop # 4

We are planning our fourth interactive workshop on synthetic displays for Sept. 4 - 5, 1996. We anticipate beginning at 8 AM on Wednesday and winding up about 4 PM on Thursday. The idea is to have the participating pilots fly several symbology concepts and to have all participants make suggestions, which we will try to implement "then and there" so they could iteratively help us arrive at a better understanding of synthetic vision displays & symbologies. While Steve Williams is programming away, we would be discussing other display issues, such as HSCT display real estate usage, other flight phase displays (cruise, surface ops), etc. We intend to address the following issues: guidance concepts/guidance modes related to pathway displays; symbology concerns from the '95 flight test (clutter, content, etc.); symbology requirements for the '96 flight test; autoflap/pitch changes during final approach; symbology concepts in general.

We have invited the following participants:

PATHWAY WORKSHOP INVITEES

PILOTS

BOEING
Paul Leckman

DOUGLAS
Mike Norman

AMERICAN AIRLINES
David Hooper

U. S. AIR
Simon Lawrence

NASA AMES
Gordon Hardy

NASA LANGLEY
Rob Rivers

FAA
Rod Lalley

RESEARCHERS

Representatives from XVS, D&I, and GFC from Boeing, McDonnell Douglas, Honeywell, NASA Ames, and NASA Langley.

Attendees

NASA Ames: Gordon Hardy, Mary Kaiser, Chima Njaka
NASA Langley: Steve Williams, Russ Parrish, Jeff Lavell, Bruce Jackson, Rob Rivers, Dave Raney, Mike Wusk, Ray Comstock

Boeing: Elfie Hofer, George Boucek, Paul Leckman
Douglas: Mike Norman
Honeywell: Andy Durbin, Tom Quinn, Thea Feyereisen
Lockheed: Lou Glaab, Patricia Hunt
Calspan: Paul Deppe
Dynacs: Chuck Anderson
American Airlines: David Hooper
U. S. Air: Simon Lawrence
Private Consultant, Purdue University (retired): Dean Nold
USAF: Barry Bryant
CSC: Trey Arthur

XVS Symbology Workshop III

NASA Langley Research Center

4-5 September

Outline

- Introduction
- Goals
- Products
- Assumptions
- Scenarios
- Issues

Introduction

- **Background**
  - Third workshop in series (previous...)
  - 18 pilots, 3 million engineers...
  - Flight test, simulation
- **Participants (introductions)**
- **Administrative**
  - Locations (lab, cafeteria, phone, copy machine, fax, computers, etc)
  - Contact information

Goals

- **Address Critical XVS Symbology Issues**
  - Clutter
  - Stereo methodology for declutter
  - Autoflap transition
  - Pathway philosophy concerns
- **Develop/Investigate improved symbology sets and philosophy**
  - Use in flight test and simulation experimentation
  - Incorporation in candidate concepts

Products

- **Minutes Summary**
- **XVS Symbology Baseline Update**
  - Export to GFC
- **Symbology Issues**

Assumptions

- **HSCT Aircraft, early next century**
- **Mission and environment equivalent to B-747-400, MD-11**
- **Avionics suite equivalent to B-777; appropriate interfaces**
- **Precision GPS (smoothed) available and operational**
- **No forward facing windows**
- **Side by side pilots, one primary XVS display per pilot**
  - Crew interface issues not covered per se in workshop
- **Side windows installed (possible electrochromics)**

Scenarios

- **Approach and Landing**
  - New Denver Airport graphics
  - Constructed approach paths for this evaluation (curved segments, 2 mile final course intercept)
- **Intercept and follow pathway to landing**
- **Missed approach**
- **Workshop conduct: fly, discuss, fly, discuss, ...**
- **Implementation: Steve Williams**
- **Minutes:**

Declutter Discussion

- **Potential decluttering methodology:**
  - color coding
  - “no draw” zones (occlusion)
  - transparency
  - stereo
  - move symbols away from flight path
  - auto switching logic
    - functional need
    - phase of flight
  - manual switching

Declutter

- **Three levels of declutter for airspeed and altitude readouts**
  - Tape displays
  - Digital displays
  - Auto switching between tape and digital
- **Autoswitching logic**
  - error from desired state (5 knots or 50 feet)
  - ground proximity initiation
  - rapid change in state (1 kt/sec or 500 ft/min)

Flight Path Vector Discussion

- **Commanded gamma versus actual gamma**
  - Actual gamma
    - lags somewhat in HSCT class acft
    - accurate in all phases
  - Commanded gamma
    - follows control inputs more closely
    - better with large inputs up and away (i.e., go-around, maneuvering)
    - problems in flare
  - Problem: what to display when actual and commanded gamma differ?
    - "ghost" gamma
    - actual gamma
    - commanded gamma

Pathway Discussion

- **What is a pathway?**
  - prospective or actual cleared ground path (lateral, and/or vertical)
- **When should a pathway be displayed?**
  - always
  - only when a defined ground path clearance exists (i.e., cleared direct, cleared on route, cleared for approach, etc)
    - problems with heading clearances, lateral only clearances, above or below clearances
- **How should a pathway be displayed?**
  - color
  - dimensions (RNP?)

Guidance Discussion

- **What type of guidance?**
  - flight director (circle, cross hairs, etc)
  - pursuit "follow-me aircraft"
- **When to display?**
  - always (what happens when pegged?)
  - when near desired path (tolerance?)
  - when selected
- **How to display**
  - color
  - changes with flight phase (transition)
  - display control laws

Minutes from the Fourth XVS Symbology Workshop
September 4-5, 1996

Summary:

XVS and the Flight Deck Integrated Display Symbology Team, with representatives from D&I, GFC, and XVS, held the Fourth Symbology Workshop on September 4th and 5th. The workshop objectives were to examine and resolve the common use XVS symbology issues associated with the pilot-in-the-loop flight, ground, and simulation experiments for the flight deck program, to further explore critical XVS symbology issues (with emphasis on declutter techniques) and initiate within the group an exploration of surface operations symbology issues. The method of exploration and resolution was based solely on subjective evaluation and group discussion, with a recognized need for more formal determinations to proceed in a quantitative data gathering setting.

In addition to a valuable exchange of freely-flowing information, with the main theme being that "less is best, least we obscure the rest (the visual scene and possible hazards)", the team determined the minimum XVS symbology set to be used throughout the flight deck program, assuming the associated use of a head-down PFD. The team also selected additional symbologies that might be augmented to the XVS display in research explorations within the flight deck program, assuming that such research would pay a proper concern for clutter.

Detailed Minutes:

The workshop utilized the simulation capability assembled by Steve Williams. SGI Reality 2 computers were used to provide the XVS visual scene, the XVS symbology sets, and the head-down EFIS displays (PFD and Nav) to VISTAS. A generic transport model with HSCT-like properties was also implemented on the SGI equipment, with a make-shift autopilot interface necessitated by the failure of the AGCU. Heavy traffic around the airport approach area was provided to explore clutter concerns.

The Minimum XVS Symbology Set

(assuming the associated use of a head-down PFD)

The team determined the minimum XVS symbology set to be used throughout the flight deck program, assuming the associated use of a head-down PFD. The minimum symbology set is documented in the following paper:

Fall 1996 XVS Workshop:

Minimal HUD Symbology Set Definition

by

Steve Williams
Crew Vehicle Integration Branch
NASA Langley Research Center

September 11, 1996

Symbology Elements

The XVS Workshop Minimal HUD is a combination of 12 symbology elements as seen in Figure 1. In this depiction, all elements except element numbers 2, 3, and 4 are displayed with a contrast enhancement technique called 'haloing.' Haloing involves first drawing the element in black with a thick pen (3 or 4 pixels wide), and then in white (or the elements chosen color) in a thinner pen (1 or 2 pixels wide). It is recommended that some contrast enhancing technique is used on all HUD elements.

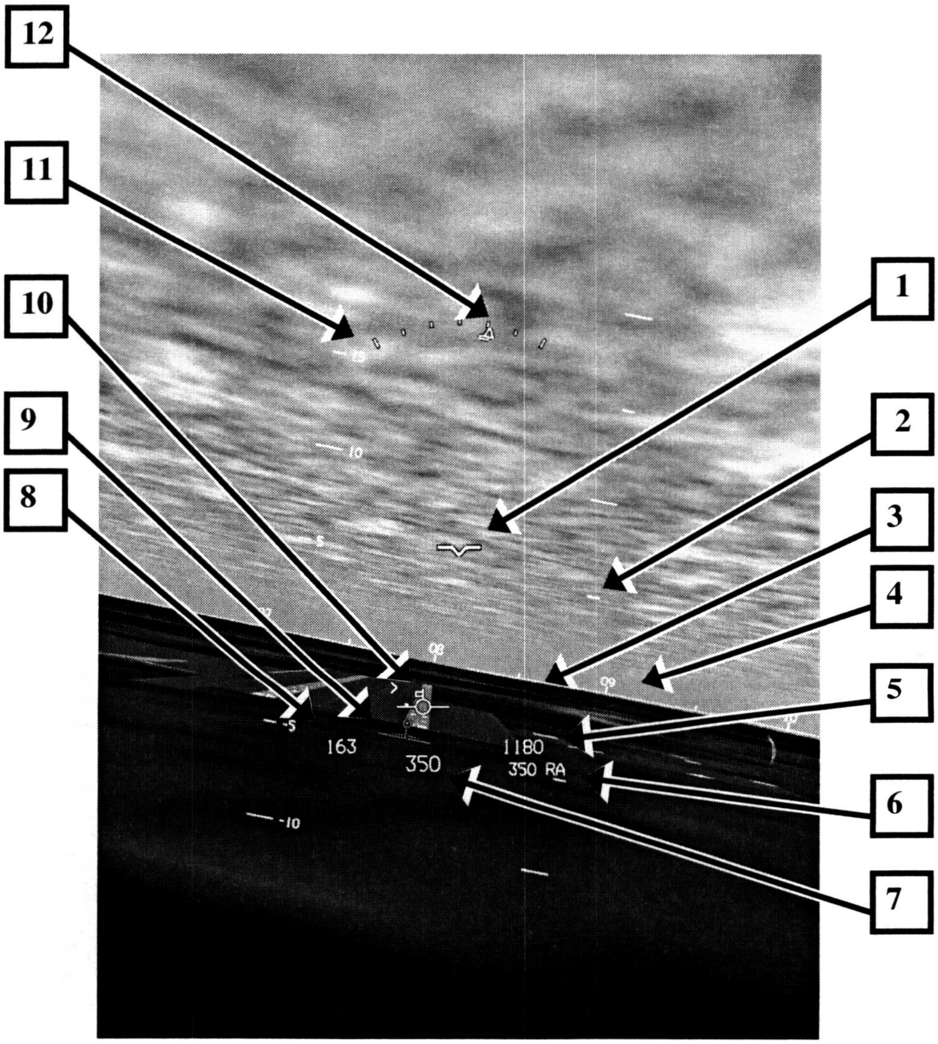

Figure 1. XVS Workshop Minimal HUD

1. Aircraft (pitch) symbol reference.

This symbol represents the waterline of the aircraft, and in combination with the pitch ladder (element 2), indicates the current pitch angle of the aircraft. The symbol is a single V with wings and has a total width of 2.4 degrees and a height of 0.4 degrees. Each wing is 0.8 degrees in length. This symbol is fixed to the display surface (does not move) as the XVS system is attitude centered.

2. Pitch Ladder.

The Pitch Ladder consists of large (1.5 degrees wide) tick marks at 10 degree intervals and short (0.7 degrees wide) tick marks at 5 degree intervals. The outside edges of the ticks are aligned and the left side of the ladder is labeled. The outer sides of the ticks are 17 degrees apart. The pitch ladder slides left and right along the horizon so that the flight path vector symbol (element 10) is always in the center of the ladder.

3. Horizon Line.

The horizon line extends across the display at the 0 degree point of the pitch ladder. The horizon line has a 4 degree gap centered around the flight path vector symbol (element 10).

4. Compass Heading Numbers and Ticks.

Along the horizon line (element 3), there are compass ticks every 5 degrees. Every ten degree tick is labeled. The 5 degree ticks are 0.3 degrees tall and the 10 degree ticks are 0.4 degrees tall. The heading numbers are centered above the ticks and are 0.5 degrees in height. Heading numbers and ticks are clipped out of (not drawn) in a region that is +- 1.0 degree on either side of the center of the horizon line gap (element 3). NOTE: The 80 degree heading indication and tick mark in Figure 1 are incorrectly displayed.

5. Barometric Altitude.

The center of the barometric altitude numeric readout is located 4.5 degrees to the right and 2.0 degrees down from the center of the flight path vector symbol (element 10). This symbol moves with the flight path vector symbol and pegs on the edges of the display. The barometric altitude numerical readout is 0.75 degrees in height and the value is truncated to 20 foot increments. The digits roll as they change, rather than discretely incrementing.

6. Radar Altitude.

The center of the radar altitude numeric readout is located 4.5 degrees to the right and 3.2 degrees down from the center of the flight path vector symbol (element 10). This symbol moves with the flight patch vector symbol and pegs on the edges of the display. Four dashed lines ("- - - -") are displayed when the radar altitude is invalid (above 2500 feet AGL). The radar altitude is truncated to 10 foot increments above 50 feet, 5 foot increments above 10 feet and below 50 feet, and 1 foot increments below 10 feet. The radar altitude is adjusted to read '0' at main gear touch down at a nominal flare attitude. The radar altitude numeric readout is 0.7 degrees in height. The letters 'RA' are displayed next to the radar altitude numeric readout at all times (even when dashed). The digits roll as they change, rather than discretely incrementing.

7. Landing Phase Radar Altitude.

At 500 feet AGL, the LAnding PHasE Radar ALTitude (LAPHER ALT) numeric readout appears. Once the LAPHER ALT is displayed, the radar altitude must ascend above 550 feet AGL before it is removed. The readout is located 3.0 degrees down from the flight path vector symbol (element 10) and is 0.85 degrees in height. The LAPHER ALT moves with the flight path vector symbol and pegs on the edges of the display. The digits roll as they change, rather than discretely incrementing.

8. Indicated Airspeed.

The indicated airspeed is located 4.5 degrees to the left and 2.0 degrees down from the center of the flight path vector symbol (element 10). This symbol moves with the flight path vector symbol and pegs on the edges of the display. The indicated airspeed numerical readout is 0.75 degrees in height and the value is truncated to 1 knot increments. The digits roll as they change, rather than discretely incrementing.

9. Flight Guidance.

One of three types of flight guidance will be provide.

1) Traditional Flight Director guidance where a single circle is displayed (0.4 degrees diameter) in magenta indicating directly the amount of pitch and roll suggested. The pilots task is to position the flight path vector symbol (element 10) so that the flight director guidance circle is center in the flight path vector circle.

2) Ghost Aircraft Pursuit guidance where a ghost aircraft symbol is displayed according to the principles and guidelines suggested in NASA TM-104027 "Some VTOL Head-Up Display Drive-Law Problems and Solutions" (1993) by Merrick. The ghost lead time used for HSR approaches varies from 15 seconds to 5 seconds based on the following equation:

ghost lead time = (Rad Alt)/50.0
if (ghost lead time > 15.0) ghost lead time = 15.0
if (ghost lead time < 5.0) ghost lead time = 5.0

The geometric description of the ghost aircraft is described in NASA TM-102216 "A Head Up Display for Application to V/STOL Aircraft Approach and Landing" (1990) by Merrick, Farris, and Vanags. The ghost is displayed in magenta and the 'X' symbol for the beacon has been replaced by a circle 0.4 degrees in diameter.

3) 3 Degree Flight Path Reference Line which is displayed at a constant 3 degrees down from the horizon line (element 3). This symbol is a white dashed line that is 15 degrees wide and has a 3.0 degree gap in the center. The 3 degree flight path reference line slides left and right with the flight path vector symbol (element 10) so that the flight path vector symbol is always center in the gap. The 3 degree flight path reference line is always parallel to the horizon line.

10. Flight Path Vector.

The Flight Path Vector symbol is made up of four sub elements as seen in figure 2. The first element (1) is the flight path vector symbol itself. This element consists of a circle 1.0 degree in diameter, two horizontal wings 1 degree in length on each side, and one vertical tail 0.6 degrees tall. The center of the circle indicates the inertial flight path of the aircraft (track angle and gamma). The second element (2) is a side slip/skid indicator. The slip/skid flag grows in the direction of the rudder correction required. The third element (3) is a speed error tape. This tape indicates relative error to the commanded airspeed. If the tape is above the wing, the aircraft is faster than the commanded airspeed. The tape grows below the wing to indicate that the aircraft is to slow. The tape is scaled such that 1 degree of tape indicates a 20 knot speed error. The fourth element (4) is an x-body axis acceleration indication. If the carrot is above the wing, the aircraft is accelerating. If the carrot is below the wing, the aircraft is decelerating. The acceleration carrot is scaled such that a 1 degree deviation from the wing indicates 2 feet/second/second acceleration.

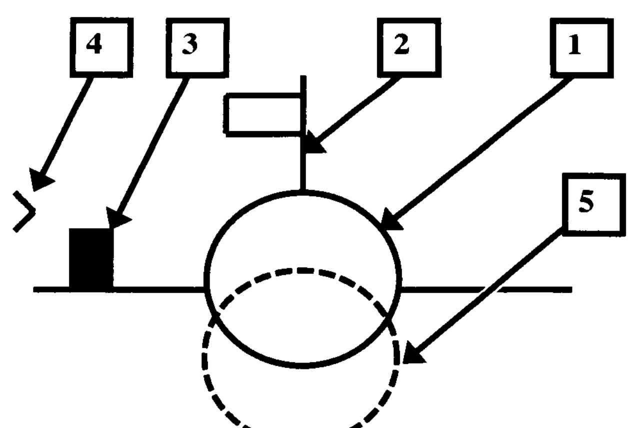

Figure 2. Flight Path Vector Symbol

11. Roll Scale.

The roll scale is a collection of tick marks nominally indicating 0, +- 10, +- 20, and +- 30 degrees of bank angle. The 0 and +- 30 degree indications are long tick marks (0.5 degrees in length), and the +- 10 and the +- 20 degree indications are short tick marks (0.25 degrees in length). If the aircraft bank angle exceeds 35 degrees, +- 45 degree ticks (short) and +- 60 degree ticks (long) are drawn. The bottom of the 0 degree roll tick mark is 11.75 degrees from the center of the display.

12. Roll Indicator.

The roll indicator symbol is a triangle that moves along the bottom of the roll scale (element 11) to indicate current bank angle. The indicator is triangle that has a base length of 0.5 degrees and a height of 0.75 degrees. Side Slip/Skid is indicated by a rectangle attached to the bottom of the roll indicator. The rectangle is 0.15 degrees tall and moves in the direction of rudder correction required.

Selected Additional Symbologies

(possible exploratory augmentations to the XVS display)

The team selected additional symbologies that might be augmented to the XVS display in research explorations within the flight deck program, assuming that such research would pay a proper concern for clutter. The symbology elements are intended to be pilot selectable and, in some cases, to utilize intelligent automatic declutter techniques. The elements are merely listed here without any discussion or description, although a few are accompanied with parenthetical notes.

1. Raw Data
2. Pathways
3. Wireframe of Active Runway with Extended Centerline
4. Airport Wireframes (runways, taxiways)
5. Terrain Lines (possibly for low visibility operations)
6. Perspective Waypoints
7. Marker Beacons
8. Touchdown Zone/Aim Point
9. Distance To Go/ Runway Remaining
10. Decision Height
11. Vertical Speed Indicator/Vertical Accleration
12. Pitch Limiting/Roll Limits
13. Flight Mode Annuciation
14. Digital Heading
15. Wind Direction (only below 500 ft ?)
16. Windshear
17. Ground Prox
18. System Messages/Allerts
19. Center Heading # (because of gap in Minimum set heading tape)
20. Commanded Heading, Course, Altitude, Speed
21. Crab Inidicator (tried line connecting pitch reference symbol [symbol # 1 in minimum set figure] and flight path vector symbol [#10])
22. Surveillance Symbols (TCAS, radar, object detection, ADS, ASDE, etc.)

Surface Operations Symbology Issues

Mary Kaiser described the initial efforts within XVS to identify surface operations symbology issues and the initial sets assembled to date. The material can be found in detail in the XVS product G4. "Initial Surface Operations Symbology Set Definition Document". M. K. Kaiser and Walter W. Johnson, NASA Ames Research Center, September 25, 1996.

The two symbology sets described included removal of the horizon line, a vertically displaced heading tape, digital readouts of ground speed with an acceleration/deacceleration carrot, a digital readout of thrust, alpha numeric routing information, and a ground track path for the airplane nose that would lead the gear-pivot-point down the taxiway centerline. Discussions covered means of removal of the horizone line after touchdown for rollout and taxi, and replacement of the horizon line for takeoff; the desirability/availablity of taximaps, airport databases; tail camera views; multiview displays; spot cameras; and other less-specific symbology issues.

Pathway Issues

- **What is a pathway?**
  - prospective or actual cleared ground path (lateral, and/or vertical)

- **Purpose of a pathway?**
  - Provide Think Ahead Information
  - Provide Corridor Representation
  - Provide Situation Awareness Enhancement
- **When should a pathway be displayed?**
  - always
  - never
  - selectable
  - only when a defined ground path clearance exists (i.e., cleared direct, cleared on route, cleared for approach, FMS has 2-D path info, FMS has 3-D path info, etc)
    - problems with heading clearances, lateral only clearances, above or below clearances
- **When should a pathway not be displayed?**
  - no ground-based constraints
  - pathway would conflict with guidance information
  - pilot decision

- **How should a pathway be displayed?**
  - color
  - dimensions (RNP?)

- **Pathway Considerations**
  - Path discontinuities
  - ATC Radar vectors/Heading Courses
  - Climb/cruise/descend phases
  - Emergency path revisions
  - Levels of Constrains (2-D, 3-D)
  - TOGA Path
  - Multi-Paths (non-active paths)

Guidance/Flight Path Vector Discussion

- **Guidance Discussion**
  - **What type of guidance?**
    - flight director (circle, cross hairs, etc)
    - pursuit "follow-me aircraft"
  - **When to display?**
    - always (what happens when pegged?)
    - when near desired path (tolerance?)
    - when selected
  - **How to display**
    - color
    - changes with flight phase (transition)
    - display control laws

- **Flight Path Vector Discussion**
  - **Commanded gamma versus actual gamma**
    - Actual gamma
      - lags somewhat in HSCT class aircraft
      - accurate in all phases
    - Commanded gamma
      - follows control inputs more closely
      - better with large inputs up and away (i.e., go-around, maneuvering)
      - problems in flare
    - Problem: what to display when actual and commanded gamma differ?
      - "ghost" gamma
      - actual gamma
      - commanded gamma

Declutter Techniques Discussion

- **Potential decluttering methodologies:**
  - color coding
  - "no draw" zones (occlusion)
  - transparency
  - stereo symbology, non-stereo scene behind
    - crossed disparity stereo
    - head tracked symbology
  - move symbols away from flight path
  - auto switching logic
    - functional need
    - phase of flight
    - manual switching

- **Declutter Techniques Demonstrated:**
  - color coding
  - transparency
  - non-head tracked stereo symbology
  - move symbols away from flight path
  - auto switching logic
    - functional need
    - phase of flight
    - manual switching
  - auto declutter implemented
    - display airspeed tape if:

      1) If there is a commanded airspeed and current airspeed is off by 5 knots or more.

      \- or -

      2) If there is a commanded acceleration and current acceleration is off by 1 knot per second or more.

      \- or -

      3) If there isn't a commanded acceleration and the absolute value of the current acceleration if greater than 2.5 knots per second.

      \- or -

      4) A new commanded airspeed is entered. (by FMC or pilot)

      \- or -

      5) If there is a new auto pilot pre-select airspeed entered (the airspeed select dial was turned on the AGCU).

      \- or -

      6) The airspeed is less than or equal to Vmin.

      \- or -

      7) It has been less than 5 seconds since any of the above has occured.

- display altitude tape if:
  1) If there is a commanded altitude and the current altitude is off by 50 feet or more.
  - or -
  2) If there is a commanded vertical airspeed and the current vertical airspeed is off by 150 feet per minute or more.
  - or -
  3) If there isn't a commanded vertical airspeed and the absolute value of the current vertical airspeed is greater than 2000 feet per minute.
  - or -
  4) A new commanded altitude is entered. (by FMC or pilot)
  - or -
  5) If there is a new auto pilot pre-select altitude entered (the altitude select dial was turned on the AGCU).
  - or -
  6) The radar altitude is lees than 250 feet.
  - or -
  7) It has been less than 5 seconds since any of the above has occured.

Other Notes

1. Consider replacing current pathway billboards with DTG readout
2. To drive the slideslip indicator (symbol # 2 on velocity vector symbol #10 in minimum set description document), use β (beta), not a_y (lateral acceleration) for HSCT.

Post Workshop

Following the four Pathway Workshops, the consensus pathway symbology was utilized in an XVS/GFC TIFS flight test as defined in Randy Bailey's version of the Steve Williams document, which follows:

Fall 1996 XVS Workshop

Minimal HUD Symbology Set Definition

Modifications for TIFS.3/FL4 Flight Test

by

Steve Williams
Crew Vehicle Integration Branch
NASA Langley Research Center

with modifications proposed by Randy Bailey

September 11, 1996
Modifications: 19 Sept 1998

Introduction

A flight test will be conducted in the Fall of 1998 using the USAF Total In-Flight Simulator (TIFS) aircraft for the NASA High Speed Research (HSR) program. This flight test will be a synergistic evaluation of both Guidance and Flight Control (GFC) and eXternal Visibility System (XVS) program elements. A common symbology set is proposed to simplify the TIFS set-up, minimize pilot training, and prevent XVS and GFC program element requirements from diverging. The basis for this common symbology set is the "XVS Minimal Symbology Set Definition" developed in a Fall 1996 XVS workshop. Modifications to this minimum set are proposed herein for the TIFS.3/FL4 flight test.

A ShibaSoku High Definition Television (HDTV) monitor will be used as the Primary XVS Display (PXD) for the TIFS.3/FL4 flight test. The anticipated field-of-view (FOV) is sketched in Figure 1. The HDTV monitor will be located in the cockpit such that an approximate 2 degree asymmetry in field-of-regard will be achieved. The total vertical FOV will be approximately 26° with 15.1° of that FOV in the nose down direction. At the nominal 11.4° approach angle-of-attack and on a 3° glideslope, approximately 4.7° will be viewable in the HDTV monitor below the TIFS flight path.

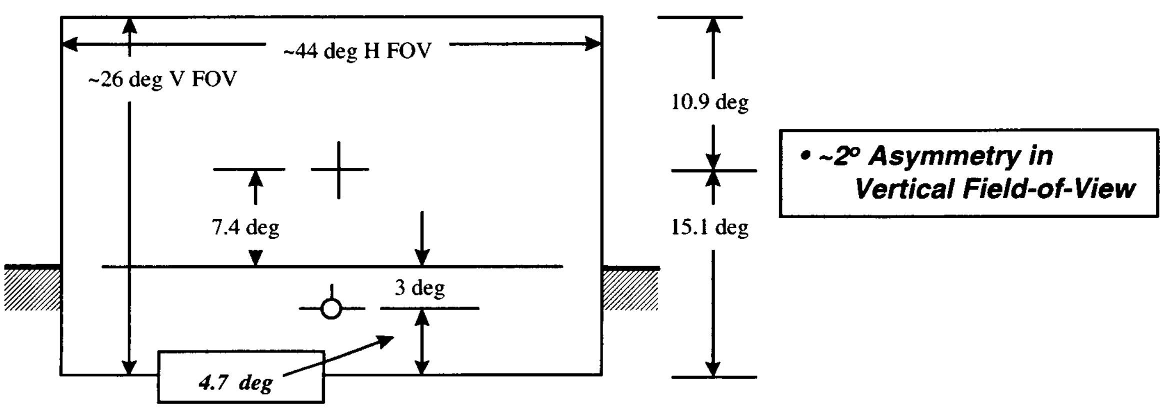

Figure 1. TIFS.3/FL4 PXD Field-of-View

Symbology Elements

The XVS Workshop Minimal HUD is a combination of 12 symbology elements as seen in Figure 2. In this depiction, all elements except element numbers 2, 3, and 4 are displayed with a contrast enhancement technique called 'haloing.' Haloing involves first drawing the element in black with a thick pen (3 or 4 pixels wide), and then in white (or the elements chosen color) in a thinner pen (1 or 2 pixels wide). It is recommended that some contrast enhancing technique is used on all HUD elements. In addition, it may be necessary to increase the pen size, enhance the haloing, or change the coloration on the symbology elements to ensure readability/legibility of the symbology for the TIFS.3/FL4 flight test.

Modifications to this minimal symbology set for the TIFS.3/FL4 flight test are presented in the following. In addition, elements 13 through 17 have been added to the minimal symbology set but are not shown on Figure 1.

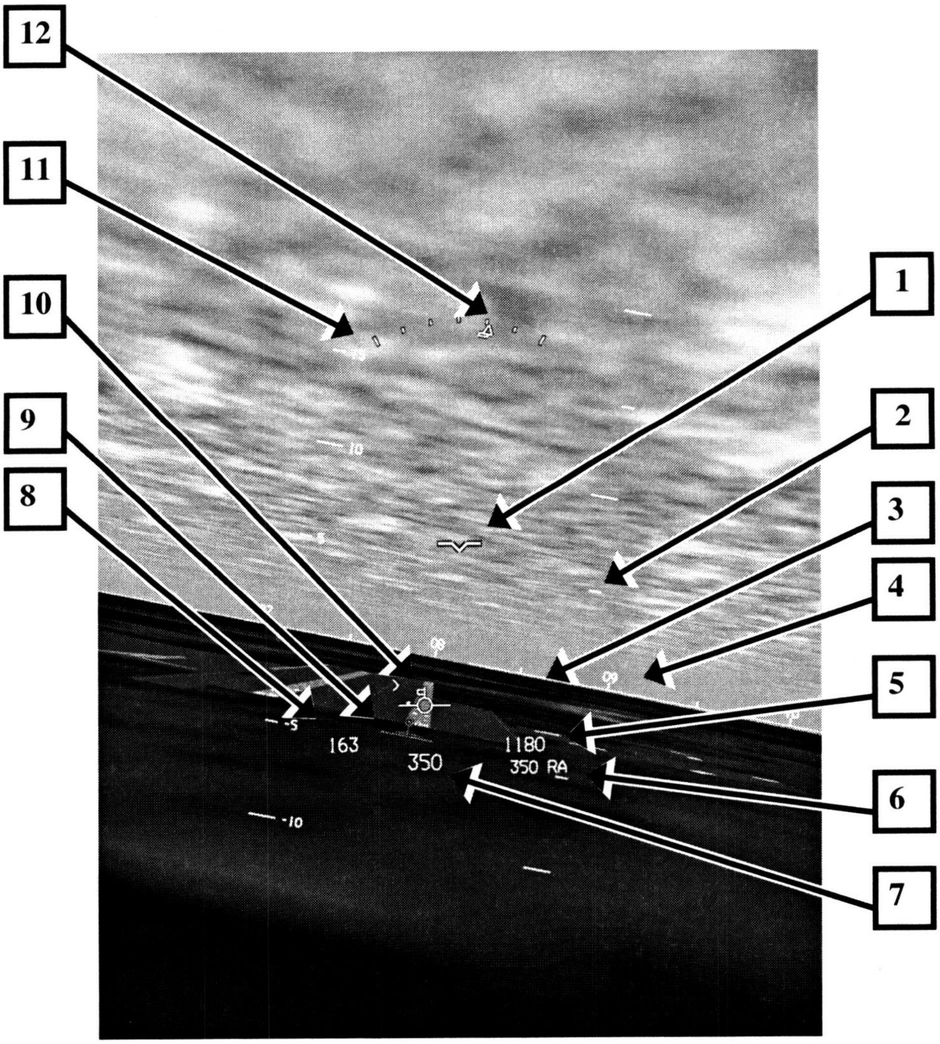

Figure 2. XVS Workshop Minimal HUD

1. Aircraft (pitch) symbol reference.

This symbol represents the waterline of the aircraft, and in combination with the pitch tape (element 2), indicates the current pitch angle of the aircraft. The symbol is a single V with wings and has a total width of 2.4 degrees and a height of 0.4 degrees. Each wing is 0.8 degrees in length. This symbol is fixed to the display surface (does not move) as the XVS system is attitude centered.

2. Pitch Tape.

The Pitch Tape consists of large (1.5 degrees wide) tick marks at 10 degree intervals and short (0.7 degrees wide) tick marks at 5 degree intervals. The outside edges of the ticks are aligned and the left side of the tape is labeled. The outer sides of the ticks are 17 degrees apart. The pitch tape slides left and right along the horizon so that the flight path vector symbol (element 10) is always in the center of the tape.

3. Horizon Line.

The horizon line extends across the display at the 0 degree point of the pitch tape. The horizon line has a 4 degree gap centered around the flight path vector symbol (element 10).

4. Compass Heading Numbers and Ticks.

Along the horizon line (element 3), there are compass ticks every 5 degrees. Every ten degree tick is labeled. The 5 degree ticks are 0.3 degrees tall and the 10 degree ticks are 0.4 degrees tall. The heading numbers are centered above the ticks and are 0.5 degrees in height. Heading numbers and ticks are clipped out of (not drawn) in a region that is +- 1.0 degree on either side of the center of the horizon line gap (element 3). NOTE: The 80 degree heading indication and tick mark in Figure 1 are incorrectly displayed.

5. Barometric Altitude.

The center of the barometric altitude numeric readout is located 4.5 degrees to the right and 2.0 degrees down from the center of the flight path vector symbol (element 10). This symbol moves with the flight path vector symbol and pegs on the edges of the display. The barometric altitude numerical readout is 0.75 degrees in height and the value is truncated to 20 foot increments.

6. Radar Altitude.

The center of the radar altitude numeric readout is located 4.5 degrees to the right and 3.2 degrees down from the center of the flight path vector symbol (element 10). This symbol moves with the flight patch vector symbol and pegs on the edges of the display. It is displayed only when radar altitude is less than 2500 ft and more than 1000 ft. Four dashed lines ("- - - -") are displayed when the radar altitude is invalid below 2500 feet AGL. The radar altitude is truncated to 10 foot increments. The radar altitude numeric readout is 0.7 degrees in height. The letter 'R' are displayed next to the radar altitude numeric readout at all times (even when dashed).

7. Landing Phase Radar Altitude.

At 1000 feet AGL, the LAnding PHasE Radar ALTitude (LAPHER ALT) numeric readout appears. Once the LAPHER ALT is displayed, the radar altitude must ascend above 1050 feet AGL before it is removed. The readout is located 3.0 degrees down from the flight path vector symbol (element 10) and is 0.75 degrees in height. The LAPHER ALT moves with the flight path vector symbol and pegs on the edges of the display. The radar altitude is in 10 ft increments above 500 ft. 1 ft increments are used below 500 ft.

8. Indicated Airspeed.

The indicated airspeed is located 4.5 degrees to the left and 2.0 degrees down from the center of the flight path vector symbol (element 10). This symbol moves with the flight path vector symbol and pegs on the edges of the display. The indicated airspeed numerical readout is 0.75 degrees in height and the value is truncated to 1 knot increments.

9. Flight Guidance.

Guidance will not be provided in the TIFS.3/FL4 flight test with the exception that a Glidepath Reference Line will be displayed when the the "landing mode" configuration has been selected. The Glidepath Reference Line will be drawn to a constant value (appropriate for the landing runway) down from the horizon line (element 3). This symbol is a white dashed line has a 3.0 degree gap in the center. 3 dashes, each 1 degree in length separated by 1 degree gaps, are displayed left and right of the flight path vector symbol. The Glidepath Reference Line slides left and right with the flight path vector symbol (element 10) so that the flight path vector symbol is always center in the gap. The Glidepath Reference Line is always parallel to the horizon line.

10. Flight Path Vector.

The Flight Path Vector symbol is made up of five sub elements as seen in Figure 3. The first element (1) is the flight path vector symbol itself. This element consists of a circle 1.0 degree in diameter, two horizontal wings 1 degree in length on each side, and one vertical tail 0.6 degrees tall. The center of the circle is driven in elevation from the gamma-dot/v control law. Above 500 ft radar altitude, the symbol represents the commanded vertical flight path angle (γ_c). Below 500 ft, the symbol is a quickened or blended combination of actual flight path (γ) and commanded flight path (γ_c). In azimuth, the symbol always represents the aircraft's ground track. The second element (2) is a side slip/skid indicator. The slip/skid flag grows in the direction of the rudder correction required. The third element (3) is a speed error tape. This tape indicates relative error to the commanded airspeed. If the tape is above the wing, the aircraft is faster than the commanded airspeed. The tape grows below the wing to indicate that the aircraft is too slow. The tape is scaled such that 1 degree of tape indicates a 20 knot speed error. The fourth element (4) is an indication of the acceleration along the flight path. This symbol is driven from the gamma-dot/v control law. If the carrot is above the wing, the aircraft is accelerating. If the carrot is below the wing, the aircraft is decelerating. The acceleration carrot is scaled such that a 1 degree deviation from the wing indicates 1 kts/second acceleration. The fifth element (5) is the actual flight path reference symbol. This "ghosted" flight path marker is displayed if the actual and commanded flight path deviate by greater than a preset value and duration. These magnitude and persistence values are contained in the gamma-dot/v control law. The symbol will be a dashed circle, 1 degree in diameter, of a magenta color.

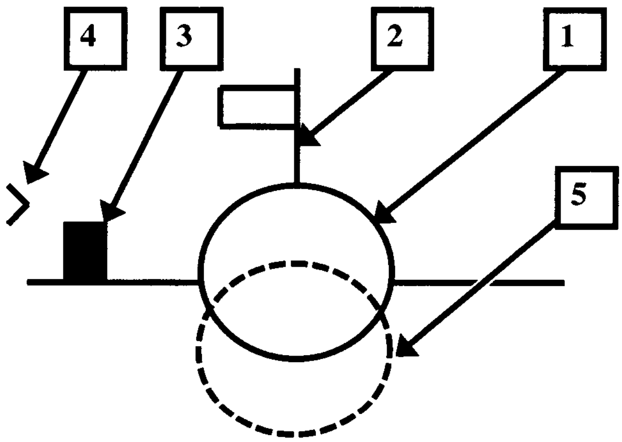

Figure 3. Flight Path Vector Symbol

11. Roll Scale.

The roll scale is a collection of tick marks nominally indicating 0, +- 10, +- 20, and +- 30 degrees of bank angle. The 0 and +- 30 degree indications are long tick marks (0.5 degrees in length), and the +- 10 and the +- 20 degree indications are short tick marks (0.25 degrees in length). If the aircraft bank angle exceeds 35 degrees, +- 45 degree ticks (short) and +- 60 degree ticks (long) are drawn. The bottom of the 0 degree roll tick mark is 10.0 degrees from the center of the display.

12. Roll Indicator.

The roll indicator symbol is a triangle that moves along the bottom of the roll scale (element 11) to indicate current bank angle. The indicator is triangle that has a base length of 0.5 degrees and a height of 0.75 degrees. Side Slip/Skid is not indicated.

13. Heading.

The aircraft magnetic heading will be digitally displayed 1.5 degrees below and centered in azimuth about the 0 degree roll scale indication. The numerics will be 0.5 degrees in height. Leading zeros will be used to provide three digit read-out at all times.

14. Flare Cue.

The flare cue (Figure 4) consists of four line segments each 1 degree in length. The vertical position of the symbol is driven from a gamma-dot/v control law command output. The azimuth position of the symbol is the same as the flight path vector azimuth position. A nominal separation of 10 pixels is planned between vertical line pairs.

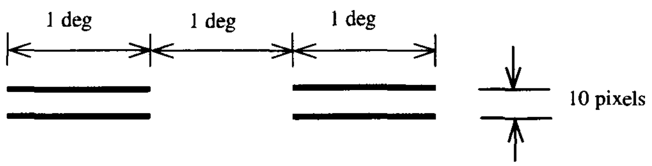

Figure 4. Flare Cue Symbol

15. Glideslope and Localizer.

Raw glideslope and localizer data will be provided when the "landing mode" configuration has been selected. Deviation will be shown in dots with a rectangle denoting zero deviation and two dots displayed at all times on either side of the zero deviation rectangle. A diamond symbol will indicate the deviation as a "fly-to" reference.

The glideslope indicator is a scale consisting of four circles (0.2 degrees in diameter) vertically separated by 1.0 degree increments about a center rectangle (0.2 degrees in width, 0.1 degrees in height). The indicator elements are laterally centered. The glideslope indicator is a diamond (outline) that is 0.4 degrees tall and 0.4 degrees wide. The center point definition of the glideslope indicator element is given as the middle of the center rectangle.

The localizer indicator is a scale consisting of four circles (0.2 degrees in diameter) horizontally spaced in 1.0 degree increments about a center rectangle (0.2 degrees in height, 0.1 degrees in width). The indicator elements are vertically centered The localizer indicator is a diamond (outline) that is 0.4 degrees tall and 0.4 degrees wide. The center point definition of the glideslope indicator element is given as the middle of the center rectangle.

The glideslope and localizer indicators will be positioned as a group. The nominal position for the glideslope indicator will be 10.0 degrees to the right and 7.5 degrees below the pitch reference symbol. The nominal position for the localizer indicator will be 15.0 degrees below the pitch reference symbol. The positions of these indicators may change depending upon the flight path vector symbol location. Unless the glideslope indicator is at the right field-of-view limit of the display, the glideslope indicator will never be positioned less than 7 degrees nor greater than 14 degrees from the flight path vector symbol. When the position of the glideslope indicator is changed, the localizer indicator will move proportionally to maintain its spatial relation to the glideslope indicator. Similarly, unless the localizer is at the bottom field-of-view limit of the display, the localizer indicator will never be less than 5 degrees nor greater than 7.5 degrees from the flight path vector symbol. When the position of the localizer indicator is changed, the glideslope indicator will move proportionally to maintain its spatial relation to the localizer indicator.

16. Wind Indicator.

The wind indicator symbol consists of an arrow pointed in the direction of the wind vector and a digital readout showing the wind speed (or total magnitude of the wind vector). The center of the wind indicator (arrow and digital readout) is located 11.5 degrees to the right and 9.75 degrees above the center of the display and is fixed to the display. The arrow is 1.1 degrees long. The shaft is 1.5 degrees long and the head is 0.3 degrees wide and 0.6 degrees tall. The numeric readout is 0-.5 degrees tall.

17. Time Code and Event Marker.

A digital numeric display will show the current time broadcast over the data bus to the PXD and associated XVS processing elements. This display will include: 1) date and, 2) time resolved to the tenth of seconds. Further, a rectangular box will be drawn around the time code when an event mark has been triggered. The numeric readout will be 0.5 degrees in height.

Concluding Remarks

The series of interactive workshops held at Langley to investigate tunnel-, pathway- or highway-in-the-sky concepts produced valuable discussion material, several promising techniques for effective pathway symbology manipulation, a consensus pathway concept for XVS application, and freely available graphics software that rendered the several different pathway concepts. Both the ideas and the actual distributed graphics software have been acknowledged by many as having been a major influence in renewed interest in this area of advanced symbology for enhanced situation awareness and precise flight guidance. The success of these workshops can only be attributed to the contributions of the government and industry display designers, test pilots, and airline pilots who participated, and to the Langley staff (particularly the graphics software virtuoso Steve Williams) that enabled the fly-and-discuss (in an iterative manner) environment. Special acknowledgements are made to Terry Abbott, Steve Williams, Mike Norman, Dave Hooper, Mike Johnson, Tom Sharpe, Mary Kaiser, Randy Harris, and Randy Bailey for some of the written material used above.

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13. ABSTRACT (*Maximum 200 words*)
In 1994-96, Langley Research Center held a series of interactive workshops investigating highway-in-the-sky concepts, which enable precise flight path control. These workshops brought together government and industry display designers and pilots to discuss and fly various concepts in an iterative manner. The primary emphasis of the first workshops was the utility and usability of pathways and the pros and cons of various features available. The final workshops were focused on the specific applications to the eXternal Visibility System (XVS) of the NASA High-Speed Research Program, which was concerned with replacement of the forward windows in a High-Speed Civil Transport with electronic displays and high resolution video cameras to enable a "No-Droop" configuration. The primary concerns in the XVS application were the prevention of display clutter and obscuration of hazards, as the camera image was the primary means of traffic separation in clear visibility conditions. These concerns were not so prominent in the first workshops, which assumed a Synthetic Vision System application in which hazard locations are known and obscuration is handled easily. The resulting consensus concept has been used since in simulation and flight test activities of many Government programs, and other concepts have been influenced by the workshop discussions.

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