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DEVELOPMENT OF A NON-DISTRIBUTED FLIGHT REFERENCE SYMBOLOGY FOR HELMET-MOUNTED DISPLAY USE DURING OFF-BORESIGHT VIEWING

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The primary purpose of the helmet-mounted display (HMD) for the fixed-wing tactical application is to provide target acquisition information to the pilot. The HMD and the information associated with it should first be designed to get the pilot's eyes on a target and to help lead a weapon sensor to a point of interest. In parallel arises both the capability and the need to provide other types of information via the HMD. For instance, ownship status information (including airspeed, altitude, heading, and attitude) can be presented to the pilot regardless of head location or movement. Off-boresight ownship status information may be useful during high off-boresight targeting tasks.

From previous research, the following conclusions are reasonable: 1) HMD presented information enhances pilots' ability to look far off-boresight for long periods of time during air-to-air tasks (Osgood, Geiselman, and Calhoun, 1991; Geiselman and Osgood, 1994). 2) Increased line of sight (LOS) duration and angle off-boresight occurs independent of HMD information functionality (targeting vs. ownship status information) (Geiselman and Osgood, 1994; Geiselman and Osgood, 1995a). 3) During simulation and test flight trials, pilots prefer that off-boresight ownship information be included within the HMD symbology set (Osgood et al, 1991; General Dynamics, 1992; Boehmer, 1994; Geiselman and Osgood, 1994; Osgood and Chapman, 1997; Fechtig, Boucek, and Geiselman, 1998). 4) Specific symbology formats should be designed to minimize occlusion and clutter (Fechtig et al, 1998).

HMD use may result in increased targeting situation awareness (SA) but the effects of spending more time looking farther off-boresight on the spatial orientation component of overall SA is not yet known. Because HMD equipped pilots tend to look farther off-boresight for longer periods of time versus HUD only pilots, it follows that the HMD should contain some of the information the pilots would otherwise scan when looking forward into the cockpit. The display of ownship status information within the HMD field of view (FOV) is an example of this type of information. For our purposes, ownship status information is intended to keep the pilot informed of the primary flight parameters while targeting tasks are being performed. The information is further intended to keep the pilot from becoming spatially disoriented. The information is not necessarily intended to be used as a recovery aid for incidences of spatial disorientation.

Ownship status information includes at least airspeed, altitude, heading, and attitude. It is anticipated that this information will be useful during low-light and degraded visual conditions at viewing angles outside of the cockpit and HUD FOV. The challenge to the designer is to develop symbology that supports all the display information tactical objectives without adversely affecting the primary utility of the HMD. This means the symbology has to be highly usable compared to any associated cost and clutter incurred by its presence. It is not acceptable for HMD ownship status information to cause spatial disorientation or any other significant distraction from the primary objective of the information source.

The present paper describes an ownship status symbology set being developed by the Air Force Research Laboratory (AFRL) to enhance information affordance of future operational HMDs. The requirements of a successful HMD ownship status symbology set are understood to be an information source that adds to the operational utility of the HMD by increasing lethality and survivability for day, night, and all weather application.

HMD ownship information design principles:

The following are general HMD ownship status symbology assumptions and design principles which have been derived from empirical research and flight test feedback. The design principles were used as basis for the development of a new HMD ownship status symbology. The intent of the new design is to increase the information conveyance and utility of the HMD while minimizing the negative impact of adding unnecessary symbology. Following the assumptions and design principles, example symbology designs are given to illustrate the differences between a current symbol set and the new symbology which was designed to closely comply with the listed principles.

1) Off-boresight ownship status information should be included in the HMD FOV any time visual flight conditions are less than perfect.
2) The information should include ownship airspeed, altitude, heading, attitude, and possibly acceleration and vertical velocity.
3) The purpose of off-boresight ownship information is to keep the pilot aware of state changes in support of the primary HMD tactical functions. The display is intended to keep the pilot from entering an unusual attitude vs. allowing the pilot to recover from an unusual attitude while off-boresight.
4) To reduce clutter within the small HMD FOV, it is acceptable to use digital information. This supports the reduction of attentional capture.
5) Digital information should be used sparingly and in such a way that its spatial location helps convey meaning or identification. For instance, airspeed should be located left of altitude and heading should be displayed between airspeed and altitude. The basic “T” primary flight information format convention should be maintained.
6) Ownship information should be kept in close proximity to other ownship information. This is done to reduce clutter and promote space-based attention. Otherwise, clutter is spread across the display surface and a wide scan pattern is required to include all information.
7) To reduce occlusion of points of interest in the outside world, ownship status information should be located in the bottom portion of the HMD FOV for the air-to-air application and in the top portion of the FOV for air-to-ground applications.
8) Attitude information should support maneuvering throughout the aircraft performance envelope for all axes. The attitude display or ownship information suite should not be limited relative to the aircraft capability, and roll, pitch, and yaw movements should be indicated.
9) To reduce clutter and maximize usability, the attitude reference should be compressed (a ratio of visual angle subtended by the symbology to the angle represented by the symbology). This allows aircraft maneuvering to be displayed via a global display. High compression ratios promote enhanced interpretation by slowing the apparent motion of dynamic effects, but precision is reduced. Some attitude designs represent a total 180 degrees of climb/dive angle (CDA) within a visual angle of 5 degrees or less.
10) The HMD attitude reference should be flightpath based (to indicate CDA instead of pitch angle). This mechanization gives the most meaningful account of the aircraft energy state and instantaneous changes in altitude.
11) Attitude information should be forward referenced. This is done to reduce the potential of disorientation caused by coupling head and aircraft movement with attitude display changes. Forward referenced displays are also easier to “look around” versus information that is superimposed over the outside world. Additionally, forward referenced displays are not affected by tracker system lags and delays.
12) The observer perspective interpretation should be inside-out vs. outside-in.

Symbology examples:

Figure 1 represents a current HMD ownship status symbology design intended for the air-to-air targeting application. In this symbology, the basic “T” layout is not maintained because attitude information is presented below the heading reference, (although the configuration is consistent with a HUD layout). Digital ownship status information is spread across the display surface to declutter the central area of the display. An active scan is required to view the required information that is now located around the periphery of the FOV. Targeting information and ownship information are likely to occlude one another in this design because the information is distributed across the display FOV. This is especially true in the upper portion of the display where air-to-air targeting information (seeker reticle, locator line, TD box, etc.) is most likely to be displayed.

A Non-Distributed Flight Reference (NDFR) is being developed by the Air Force Research Laboratory (AFRL) as a potential source of off-boresight ownship status information for HMD application (Fig. 2). The display was designed to be in compliance with the design principles outlined above. In the NDFR, ownship

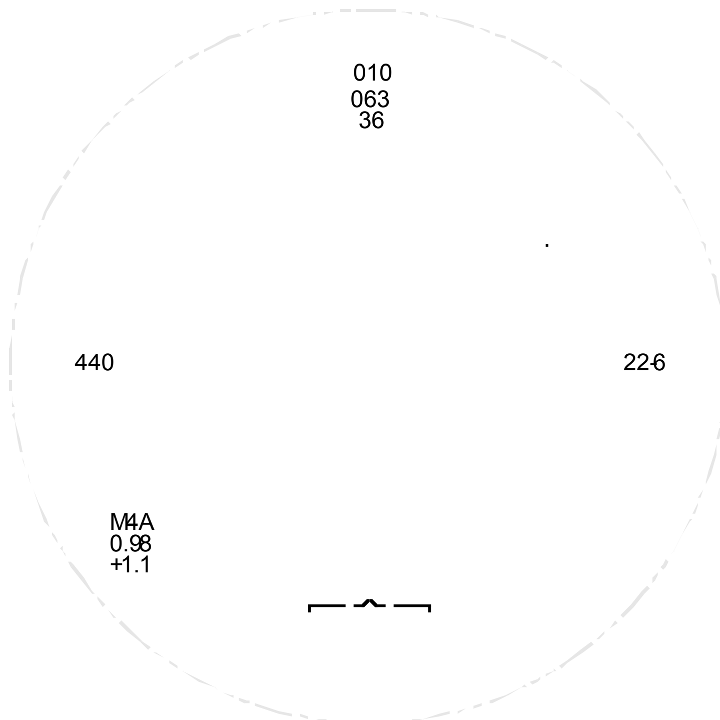

Figure 1. Symbol set which represents current HMD ownship status information design.

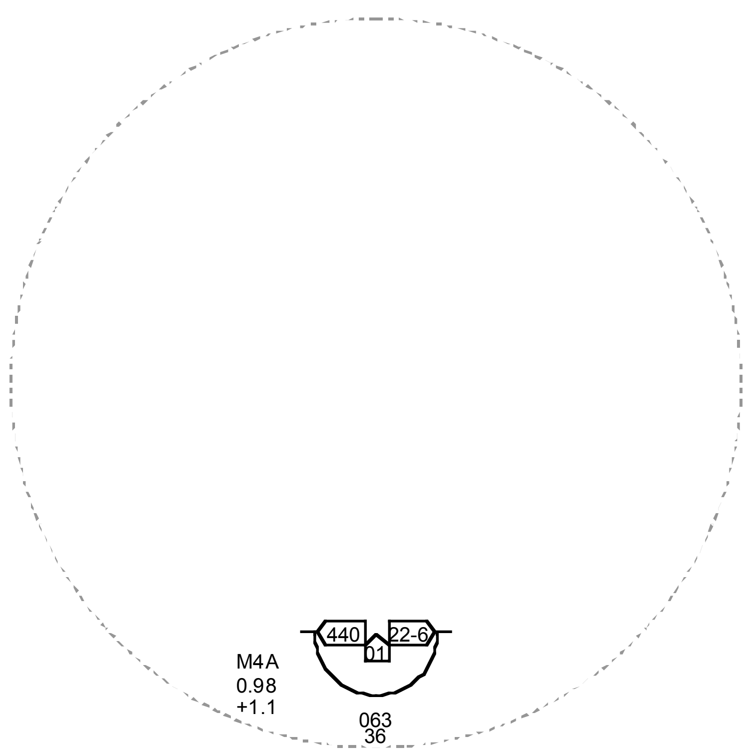

Figure 2. Non-Distributed Flight Reference symbol set.

status information is moved in close together and placed within an attitude symbology. Primary flight information is located within the display and is spatially arranged so that the conventional basic "T" layout is maintained. The display is mechanized so the attitude display is flightpath-based, compressed, and forward-referenced. The full aircraft maneuvering envelope is supported by the use of heading tags which appear at extreme climb and dive angles. For the air-to-air application, the upper area of the display is decluttered to reduce occlusion of targeting information. By not distributing symbology across the display, a compact and portable information "stamp" is created for the primary flight information. This information stamp can be located elsewhere within the HMD FOV for other applications such as air-to-ground, and the interpretation of the information does not change. The paragraphs below describe the NDFR in more detail.

NDFR primary flight symbology:

The NDFR includes airspeed, altitude, and heading information presented digitally inside an outline framework designed to mimic the shape of aircraft wings and tail (Fig. 3). The shape of the aircraft symbol is also designed to form a schematic "W" or stylized waterline across the top of the outlined information. Together these features form the ownship aircraft reference symbology for the attitude symbology. Within the aircraft reference symbol, airspeed is presented on the left (480 kts), altitude is presented on the right (22,600 ft.), and heading (90 degrees) is presented below and in-between airspeed and altitude. This configuration is consistent within the conventional basic "T" primary flight reference layout. The aircraft symbol is fixed relative to the HMD FOV and the attitude symbology moves about it. Attitude is interpreted by comparing the aircraft reference symbol to the attitude symbology.

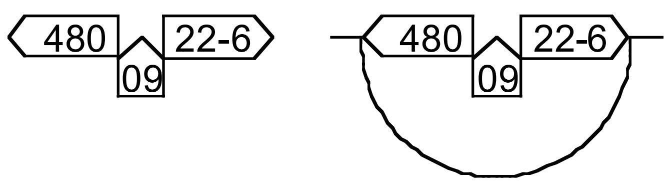

Figure 3. NDFR flight information without and with the ASAR attitude symbology.

NDFR attitude symbology features:

NDFR uses an Arc Segmented Attitude Reference (ASAR) approach for the attitude component of the symbol set. The ASAR has also been referred to as the "orange peel" display because its resemblance to a orange slice. The ASAR was originally designed by Deutsche Aerospace as a potential HUD primary flight reference symbology. The format was modified by the U.S. Air Force as a HMD attitude reference and has flown on both the X-31 and on a AV-8B aircraft as part of two separate flight evaluations (Boehmer,1994; Meador and Geiselman, 1996; Osgood and Chapman, 1997). Pilots reported that the symbology was easy to interpret and usable for global attitude maintenance. More modifications were made to the ASAR to form the present NDFR component. To support more of the aircraft maneuvering envelope, heading tags were added to the ASAR symbology to give an indication of ownship roll at extreme climb and dive angles. The heading tags are mechanized to appear when climb or dive angle reaches 80 degrees or greater. This functionality was adopted from the Theta attitude reference symbology which displays heading integrated with roll and pitch information (Geiselman and Osgood, 1995b). The following is a description of the basic NDFR attitude symbology features.

The ASAR attitude symbology includes a fixed climb/dive symbol (ownship symbol) which represents flightpath angle and roll by its relation to a half circle arc surrounding the ownship symbol (Fig. 3). During straight and level flight, the upper, or above-horizon half of the circle is not drawn. The visible lower half of the circle represents the area below the horizon. As the climb angle increases, the negative angle area of the arc begins to narrow in proportion to the climb/dive angle (Fig. 4). Conversely, with an increase in dive angle, the arc closes to form a more complete circle. The heading tags give an indication of ownship roll at

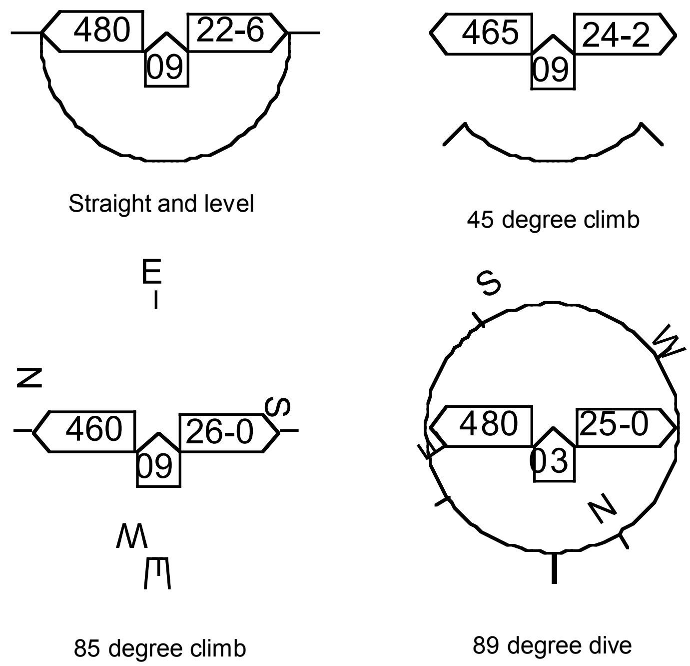

Figure 4. NDFR during various climb and dive angles.

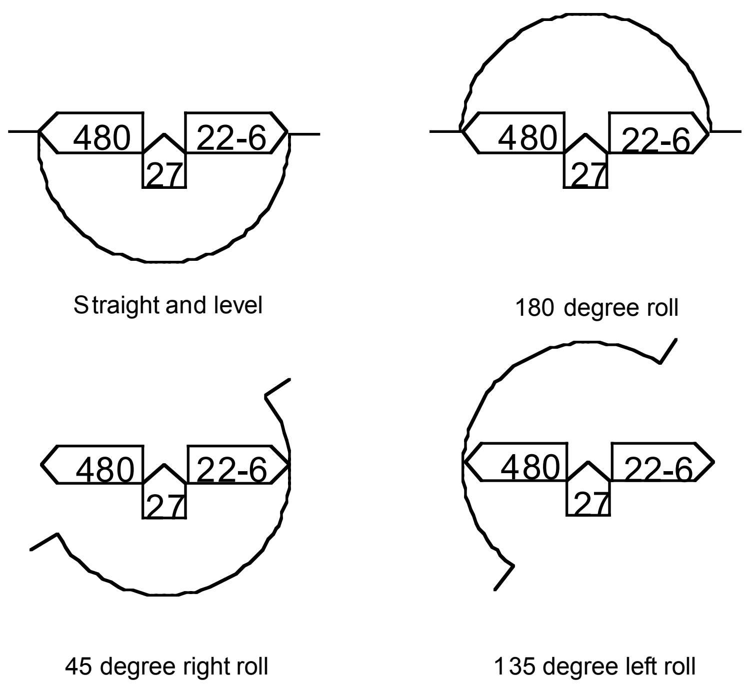

Figure 5. NDFR during roll maneuvering.

extreme climb and dive angles (80 degrees or greater). In a 90 degree dive, the arc forms a complete circle with markers to indicate the direction of the closest horizon. The opening in the arc also represents the direction to the closest horizon. This mechanization allows the following rule of thumb to be used during maneuvering back to the horizon: “roll to put the opening at the nose of the ownship symbol and pull.” The format was designed to provide the most information during critical dive attitudes (drawn circle). During level flight or a climb, the drawn symbology is located low in the display FOV to reduce obstruction. During rolling maneuvers the arc and artificial horizon rotates about the ownship symbol (Fig. 5). Typical compression of the NDFR ASAR is approximately 19:1 depending on the HMD FOV.

NDFR research and evaluation.

The NDFR needs to be evaluated against current symbology sets to determine if the new design produces performance benefits which justify the cost of its implementation. Also, research is required to refine the form and function of the NDFR. For instance, it is not known if the drawn frame around the NDFR digital information is required for the successful interpretation of the information. The modification or removal of the frame could further reduce display clutter. Also yet to be determined is the initialization angle for the pop-up heading tags. These tags are intended to give the pilot world-referenced roll information at extreme climb/dive angles. At what angles the information becomes useful (if it does at all) has not yet been investigated.

The following are recommended methodology guidelines intended to be used for HMD ownship status symbology evaluation purposes: Similar to the symbology development, held constant across the methodology design is the belief that the primary purpose of the HMD is target cueing. Therefore, representative evaluation tasks are those which include off-boresight target searching, designating, and tracking. An evaluation methodology should be designed to be flexible, so future candidate symbologies and other interface technologies, such as multi-sensory displays, can be reliably compared to previously collected data. A second objective is to develop a methodology that is both empirically and operationally valid. It should be experimentally controlled but recognized by subject matter experts as operationally relevant. The methodology should include the following features (Geiselman et al, 1998):

1) A multi-phased trial approach should be used to help ensure trial continuity. Each trial should be formed of separate phases which are treated and analyzed as separate tasks.
2) A dual task paradigm should be employed with off-boresight targeting (search, location, designation, and tracking) primary tasks.
3) The secondary tasks include flight tasks such as attitude maintenance, maneuvering, and extreme attitude maneuvering.
4) Because of the operational nature of the tasks, at least the initial evaluations should use subject matter experts as experimental subjects.
5) Independent variable manipulations should include symbology format type, a no-HMD symbology baseline condition, and natural horizon presence (on or off to simulate non-degraded and degraded visual conditions).
6) Measurement metrics should include task performance, subject behavior (head movement), and subjective feedback. Subjective feedback should include preference questionnaires, workload estimates, and situation awareness ratings.

NDFR and other applications:

Because the NDFR forms a small information stamp, it can potentially be used in other cockpit and aircraft control applications. Because the information is presented the same way wherever it is used, user interpretation should be consistent. Other uses include head-down displays, flightpath-in-the-sky enhancement, and UAV/UCAV control station applications.

Head-down displays:

NDFR symbology can be added to head-down displays which presently require pilot attention but distribute or do not include ownship status information (Fig. 6). The NDFR should be unobtrusive, but the information will be available to keep the pilot in contact with aircraft status information without an otherwise required scan of primary flight instruments or a head-up look out of the cockpit. Similarly, an NDFR approach may present sufficient information to meet stand-by flight instrumentation and cross-check requirements. In any case, the objective is to keep the pilot in continuous contact with ownship status information to thereby keep the pilot from becoming spatially disoriented. Because the NDFR form is consistent regardless of its location, display interpretation from one location to another should be seamless.

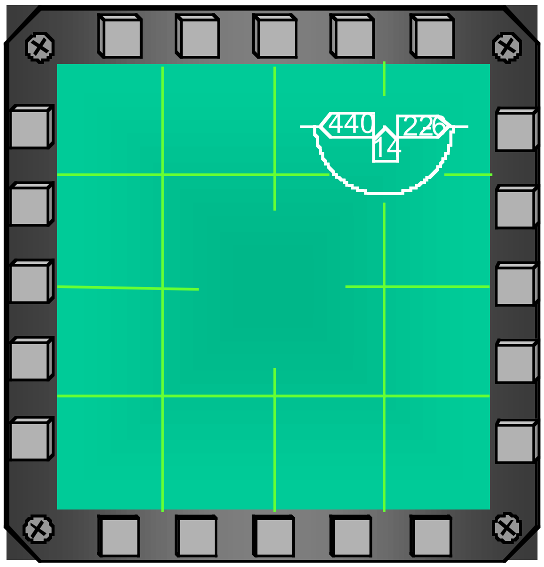

Figure 6. NDFR shown in a multi-function display application.

Flightpath-in-the-sky symbology:

Flightpath symbology (Fig. 7) gives attitude information relative to a prescribed, commanded, or predicted route of flight. This is very good for situation awareness relative to the route of flight but aircraft attitude and primary flight information for free flight over the earth is not as well supported. Coupling NDFR information to the flightpath ownship symbology may help to global ownship status awareness (Fig. 8). In conjunction with off-boresight use of the NDFR, the pilot can be kept in constant contact with basic flight information via a information source with a consistent interpretation.

UAV/UCAV control station:

The sensor information an Uninhabited Aerial Vehicle (UAV) and Uninhabited Combat Aerial Vehicle (UCAV) operator uses is similar to that available to a pilot using a limited FOV. Presently, the sensor used by the UAV operator is not coupled to the operator's LOS. A manually slewable camera or other sensor is used to give the operator visual flight feedback. The camera LOS and vehicle flightpath are seldom aligned. Additionally, the operator does not have any proprioceptive sense of LOS vs. the longitudinal axis of the air vehicle. Similar to the HMD use, NDFR like information can be used to give constant forward-referenced basic flight information regardless of sensor LOS. Also, NDFR information could be located within other ground control station mission planning and status displays to keep UAV/UCAV operators aware of the vehicle flight status.

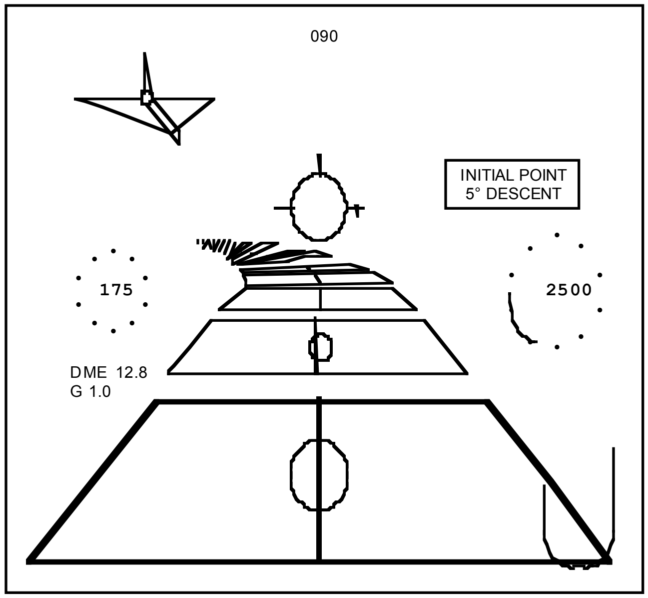

Figure 7. Flightpath-in-the-sky symbology with distributed ownship status information.

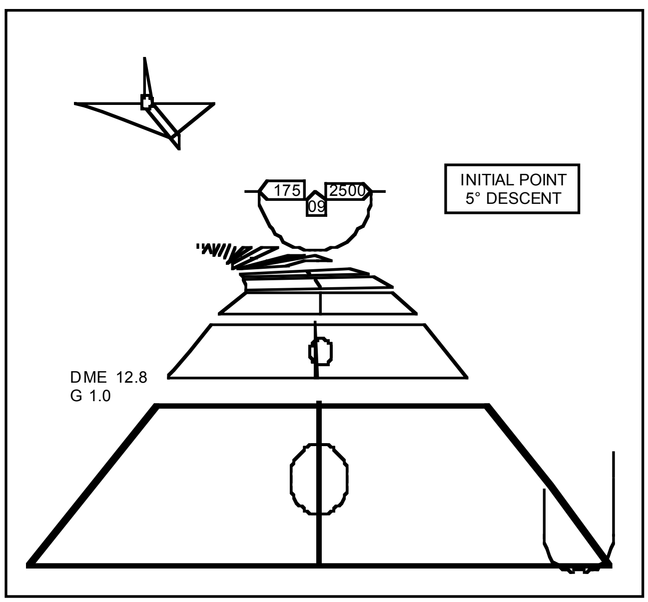

Figure 8. Flightpath-in-the-sky with NDFR ownship status information.

Conclusion:

The near-term AFRL goal is to develop a performance optimized HMD symbology set intended for present technological capability. The development of effective ownship status information symbology is a partial fulfillment of this overall goal. The general development approach includes the identification of empirically derived design principles which can be applied across diverse HMD applications. The ownship symbology set will be designed to comply with the design principles. The NDFR is an example product of this design approach. The symbology resulting from this process will form the baseline design for the first operationally fielded HMDs. Likewise, the symbology formats will be included in design guidance documentation for related applications. The NDFR symbology is a baseline ownship status symbology candidate. After the baseline symbology set is established, new designs will be added or will replace baseline formats whenever operational need, technological innovation, or demonstrated performance enhancement warrants the change. Regardless of the eventual HMD symbology format, the derived design principles and evaluation lessons learned should help ensure that the most effective symbology designs are implemented for future operational HMDs.

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