FLIGHT DECK DISPLAY TECHNOLOGIES FOR 4DT AND SURFACE EQUIVALENT VISUAL OPERATIONS

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NASA research is focused on flight deck display technologies that may significantly enhance situation awareness, enable new operating concepts, and reduce the potential for incidents/accidents for terminal area and surface operations. The display technologies include surface map, head-up, and head-worn displays; 4DT guidance algorithms; synthetic and enhanced vision technologies; and terminal maneuvering area traffic conflict detection and alerting systems. This work is critical to ensure that the flight deck interface technologies and the role of the human participants can support the full realization of the Next Generation Air Transportation System (NextGen) and its novel operating concepts.

Background

The Next Generation Air Transportation System (NextGen) concept for the year 2025 and beyond envisions the movement of large numbers of people and goods in a safe, efficient, and reliable manner. NextGen will remove many of the constraints in the current air transportation system, support a wider range of operations, and deliver an overall system capacity up to 3 times that of current operating levels. New capabilities are envisioned for NextGen, including four-dimensional trajectory (4DT)-based operations, equivalent visual operations, super density arrival/departure operations, and network-centric operations. National Aeronautics and Space Administration (NASA) research, development, test, and evaluation (RDT&E) of flight deck interface technologies is being conducted to proactively overcome aircraft safety barriers that would otherwise constrain the full realization of NextGen. As part of this work, specific research issues associated with the NextGen Terminal Maneuvering Area (TMA) are being addressed: 1) the impact of emerging NextGen operational concepts, such as equivalent visual operations (EVO) and 4DT operations; 2) the effect of changing communication modalities within a net-centric environment; and, 3) the influences from increased pilot responsibility for self-separation and performance compliance. An overview of NASA's flight deck interface technology research thrusts for these areas is described herein.

NASA Collision Avoidance for Airport Traffic

A Collision Avoidance for Airport Traffic (CAAT) research thrust has been formulated to develop technologies, data, and guidelines to enable safe TMA operations. This work expands upon existing research and technologies for tactical and strategic surface operations awareness for the flight crew and also, provides additional, protective Conflict Detection and Resolution (CD&R) functionality for NextGen operations. CAAT integrates airborne and ground-based technologies, which include flight deck displays, conflict detection and alerting algorithms, on-board position determination systems, airport surveillance systems, and controller-pilot data link communications.

Taxi-NASA Head-Up Display

Previous research has shown that the key to preventing surface traffic conflicts is to ensure that pilots know: (a) where they are located, (b) where other traffic is located, and (c) where to go on the airport surface. The CAAT concepts promote these attributes by use of several visual display interfaces including a modified head-up display (HUD) concept based on Taxiway Navigation and Situation Awareness (T-NASA) research (Foyle, Andre, McCann, Wenzel, Begault, & Battiste, 1996; McCann, Hooey, Parke, Foyle, Andre, & Kanki, B., 1998). The HUD display concepts, sketched in Figures 1 and 2, show current ground speed in digital format, the current taxiway, next cleared taxiway, centerline markers and virtual cones on the taxiway edge. Additional cues are given for turns. These cues consist of turn flags and virtual turn signs (similar to road way turn signs). Hold shorts are displayed with a single line drawn at the hold short location with a virtual stop sign (Figure 2). A non-conformal taxi director display provides an intuitive display of the relationship between the taxiway centerline and the aircraft's landing gear position. These symbology elements have been shown to significantly enhance situation awareness and navigation precision that would be required for NextGEN equivalent visual operations (EVO). The CAAT system further enhances the HUD visual interface with audible alerts for deviation from the assigned taxi route ("Off Route, Off Route") and unauthorized crossing of a hold line ("Crossing Hold, Crossing Hold").

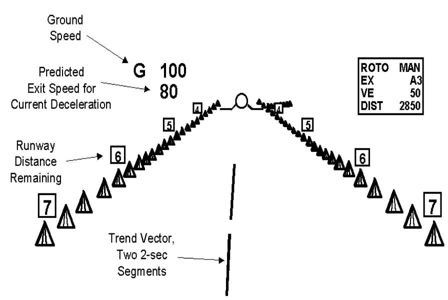

Figure 1. HUD Touchdown Symbology

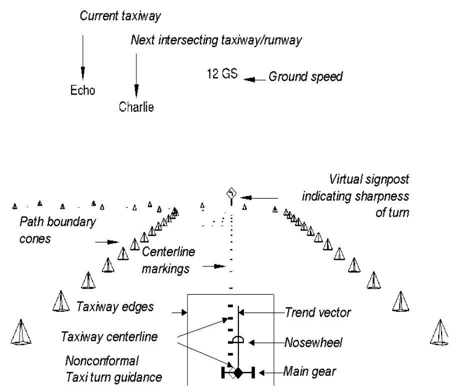

Figure 2. HUD Taxi Symbology

Conflict Detection and Alerting

A goal of CAAT is to provide an additional, protective safety layer of conflict detection and alerting for NextGen operations in the event that the tactical or strategic situation awareness (SA) is not sufficient or human errors or blunders occur. Ownship and traffic data are continually monitored to detect conflicts on the runway, at low altitudes near the airport, and during taxi and ramp operations for multiple classes of aircraft and surface vehicles. Alerts are designed for flight crew awareness and to identify potentially hazardous operational conditions that may require immediate flight crew response (Figure 3). This work builds from substantial NASA testing for runway conflict detection and alerting (Green 2006, Jones 2002 and 2005, Jones, et. al., 2001, and Jones and Prinzel, 2006), however, low altitude and taxi conflict detection is in the initial development stage.

NASA is also investigating the concept of providing advisories or warnings for potential runway safety hazards. These indications are intended to increase the flight crews' situation awareness about relevant traffic that could affect runway safety. Research regarding the feasibility of providing resolution advisories (RA) for conflicts in the TMA without producing undesired consequences is also being initiated .

NASA Surface Map and Electronic Flight Bag Display Concepts

The increasing unavailability of radio-frequency bandwidth is driving a rapid shift from voice to data-link. By 2030 85% of Air Traffic Services communications are projected to be provided via data-link in the Airport/TMA environments (Eurocontrol, 2005). Net-centric operations hope to capitalize on a data-link environment's strengths. However, previous research has demonstrated numerous flight deck problems, including increased head-down time and pilot workload (*e.g.*, Kerns, 1994; Groce & Boucek, 1987, Prinzo, 1998) which – in a NextGen environment with closer spacing and more pilot responsibility for 4DT separation – could significantly reduce safety margins. Furthermore, there are concerns of loss of "party-line" with data-link (*e.g.*, Midkiff & Hansman, 1992; Pritchett and Hansman, 1995). For these and other reasons, NASA has been investigating the effects of data-link communication and potential visual display technologies that may mitigate, or eliminate, the potential deleterious effects of a voice-by-exception data-link NextGEN TMA environment. The concepts are based on emerging navigation, surveillance, and communicative technologies, such as CPDLC-all, ADS-B (in/out), TIS-B, *etc.*). The flight deck interface concepts include electronic moving surface map concepts (Figure 3), head-up, and head-worn displays; and more critically, the information needs and modalities for the flight crew. For instance, the cockpit display of traffic information in a NextGen environment, with the addition of ADS-B intent information, may ameliorate issues of "party-line" information loss or inherent latencies in pilot-ATC communications under Controller Pilot Data-Link Communications (CPDLC), but traffic intent information may be critical to these operations. Unlike flight operations, current surface operations rely heavily on planned holds, following other traffic, and real-time updates to routing and other traffic. Without data-link intent information, these nuances may be lost and NextGen 4DT surface operations performance promises could remain unrealized.

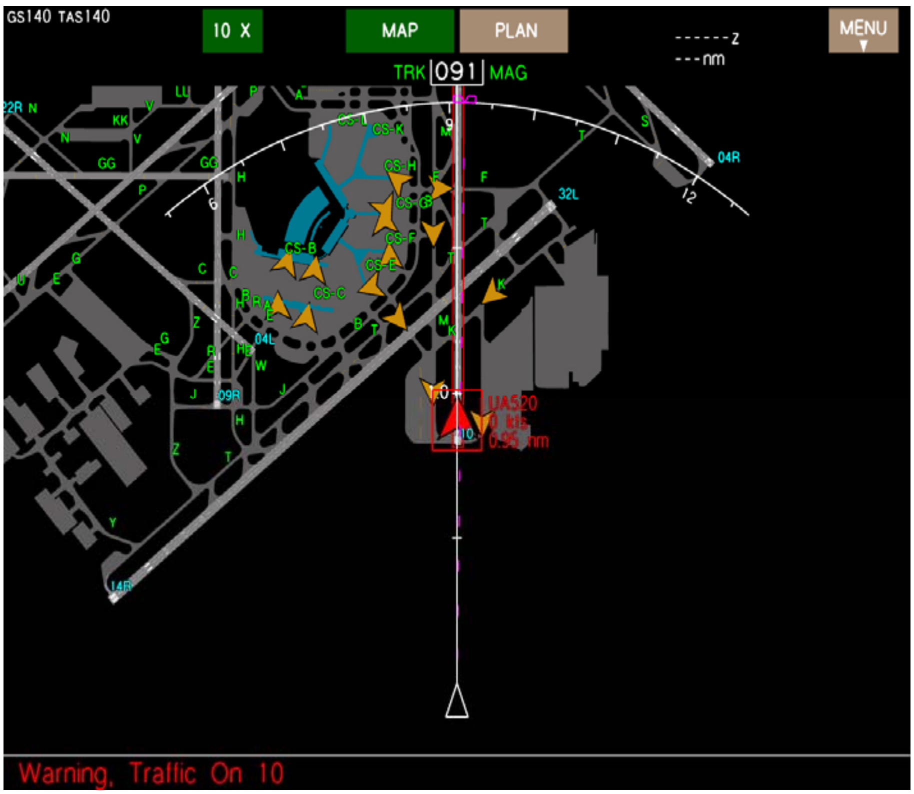

Figure 3. Runway Incursion Traffic Warning Alert (w/ audible alert)

Current research at NASA is focused on advanced surface map display concepts. The NASA surface map display provides traffic and manual query capability of other aircraft intent and graphical depiction of own-ship and target aircraft paths, and automatically prioritizes and selects aircraft, based on threat severity and/or proximity of traffic, and provides prediction and preview capability of other traffic and route conflicts. The surface map is shown in place of the ND when conducting surface operations (only on the pilot-not-taxiing side). The transition to the surface map is automatically done when on approach, the groundspeed is less than 80 knots, and all landing gear is touching the runway. Figure 4 shows the surface moving map with textual and graphical traffic icons displayed, own route graphically depicted in magenta, and the selected traffic's graphical route and state information (30 sec trend) displayed, graphical (30/60/90 sec) intent prediction. Similar required- and estimated-time-of-arrival information and commanded speeds to meet RTAs are presented on the HUD based on a T-NASA HUD symbology set (Figure 5). These display concepts are supplemented by CPDLC interfaces on the Primary Flight Display (PFD) and Electronic Flight Bag (EFB). The HUD, PFD, and EFB also present 4DT enhanced (FLIR) and synthetic vision display information and advanced tactical and strategic guidance.

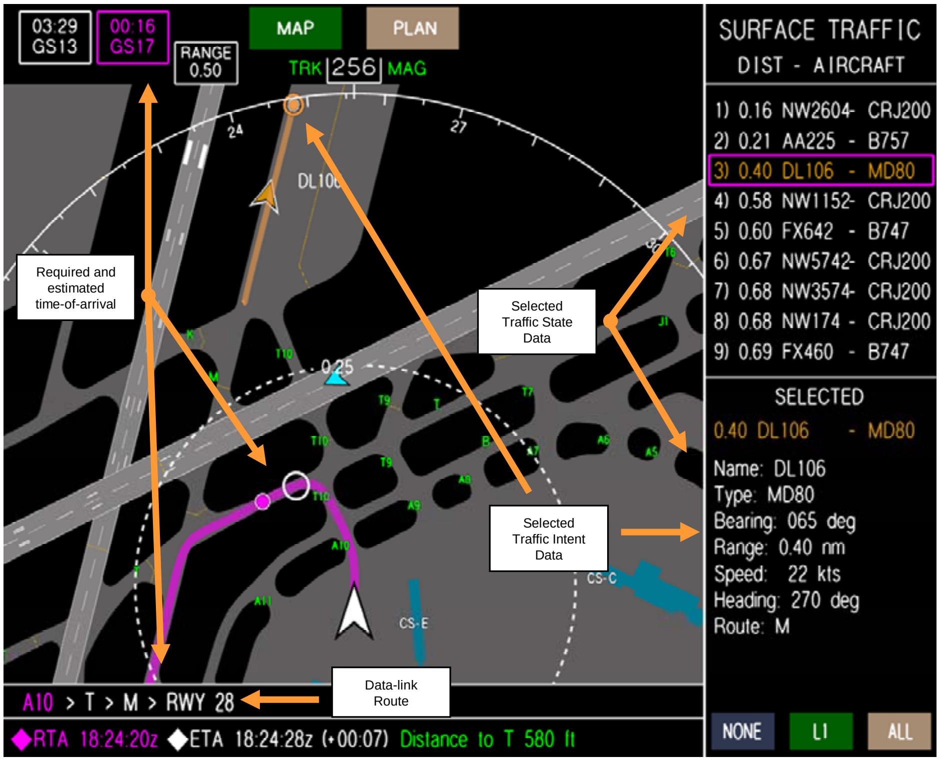

Figure 4. Example NASA Surface Map Display Concept

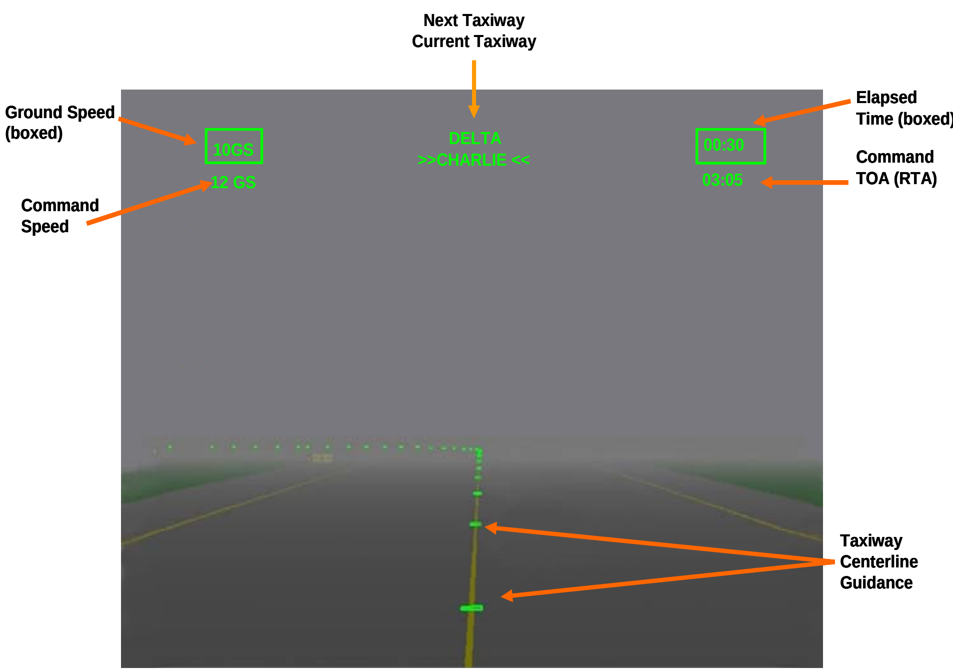

Figure 5. 4-DT Head-Up Display on Surface

NASA Head-Worn Display Concepts

Head-up, conformal information, such as that provided by the T-NASA HUD concepts, provide tactical and strategic awareness for the pilot-flying for safety and performance benefit. A major limitation of the HUD - for ground operations, in particular - is its monochrome form and limited, fixed field-of-regard. A monochromatic display has the inherent problem of being unable to use color for information de-cluttering and information cuing. Coupled with a limited field of regard, the HUD symbology must be carefully designed to optimize the information presentation to the pilot without increasing display clutter. NASA has been investigating emerging Head Worn Displays (HWDs) to resolve these limitations for NextGEN equivalent visual operations. The NASA HWD concept (Figure 6) is a head-tracked, color, unlimited field-of-regard concept that provides a 3-D conformal synthetic vision (SV) view of the airport surface integrated with advanced taxi route clearance, taxi precision guidance, enhanced vision, traffic data, and data-link capability. Simulation research (*e.g.*, Arthur, Prinzel, et al., 2006) has demonstrated significantly enhanced situation awareness, lowered workload, and taxi efficiency compared to existing head-up and head-down display technologies. The results evince the tremendous potential these displays have for enabling EVO during low-visibility complex terminal and surface operations.

Figure 6. NASA Head-Worn Display Concepts for Surface Equivalent Visual Operations

4DT Guidance Algorithms

NextGen surface traffic management (STM) concepts envision dynamic algorithms to generate speed- or time-based taxi clearances to calculate the most efficient movement of all surface traffic and enable precise surface coordination (Cheng, Yeh, Diaz, & Foyle, 2004; Rathinam, Montoya, & Jung, 2008). The STM system provides speed or time commands to the pilots at various traffic flow points throughout the taxi route to regulate the required precision of surface traffic movements. The aircraft's taxi speed may be adjusted if the pilot is unable to conform to the speed command, if traffic is unable to comply thus creating a reduction in separation, or if the needs of the dynamic airport surface require adjustment.

NextGen STM Concept Development

NextGen taxi operations represent a fundamental paradigm shift to include time-based or speed-based taxi clearances. NASA researchers are helping to define this new paradigm by considering the roles of pilots, ATC, and automation, and by defining procedural and operational requirements. Pilot-in-the-loop studies at NASA have evaluated different concept of operations including issues such as speed vs. time commands and single vs. multiple checkpoints. Advanced display concepts to support to these operations (which may be presented on a head-up display, an electronic moving map, or primary flight display) must support pilots' 4DT taxi performance without increasing pilot workload, reducing situation awareness, or promoting excessive head-down time. One recent simulation study revealed significant reductions in time-of-arrival (TOA) error when pilots taxied using error-nulling speed guidance on the primary flight display. Future studies will evaluate the impact of pilot non-conformance, and STM reliability and system failures.

STM System and Algorithm Development

Since the time-based taxi concept is in its infancy, aviation human factors researchers at NASA are working to impact the design of the STM algorithms so that the resulting STM system does not exceed human performance capabilities. Specifically, pilot-in-the-loop simulation studies are underway at NASA that investigate the effects of: flight deck display bandwidth, number of traffic flow points, and time constraint window size for RTA (Figure 7, from Foyle, Williams, & Hooey, 2008); as well as the impact of STM re-optimization (due to traffic changes and pilot performance). One recently completed simulation study characterized the distribution of pilots' TOA performance at traffic flow points to inform the development of STM algorithms with regards to the allowable time constraints of the STM system.

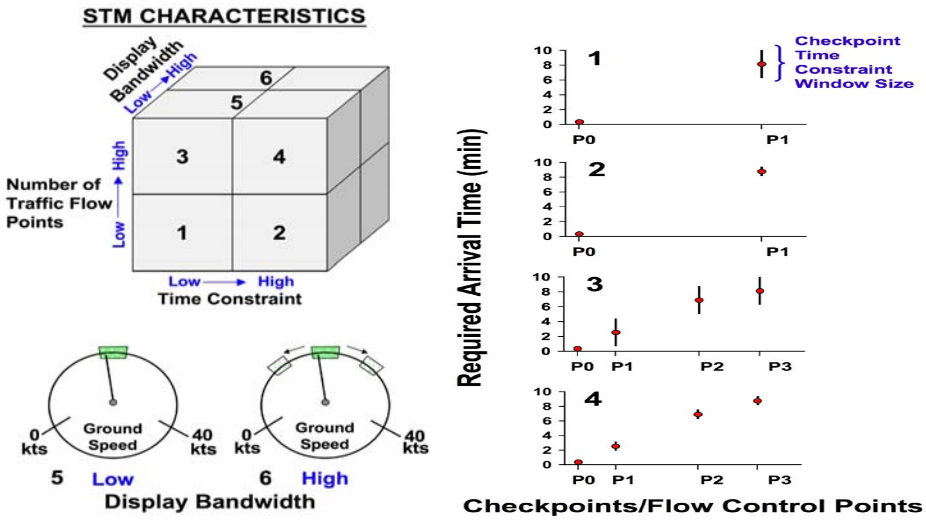

Figure 7. Characteristics of Time-based STM (Foyle, Williams, & Hooey, 2008)

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