Initial Flight Test Results of Ohio University's 3-Dimensional Cockpit Display of Traffic Information

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Abstract: **This paper discusses the initial flight test results of a 3-Dimensional Cockpit Display of Traffic Information (3D-CDTI). Ohio University's 3D-CDTI is a display format that combines existing Synthetic Vision System and Automatic Dependent Surveillance-Broadcast research. The goal of the 3D-CDTI is to contribute to the development of new display concepts for NASA's Small Aircraft Transportation System research program.**

I. INTRODUCTION

The Small Aircraft Transportation System (SATS) [1] aircraft, like current general aviation aircraft, have limited panel area that can be used for flight deck displays. To maximize the number of applications that can be provided, it is beneficial to combine functions on a single display. Integrating the 3-Dimensional Cockpit Display of Traffic Information (3D-CDTI) display into the Synthetic Vision System (SVS) equipment can maximize the benefit of the SVS display.

The Ohio University Avionics Engineering Center (AEC) SVS uses terrain databases to represent terrain features to the flight crew. These terrain databases are also referred to as Digital Elevation Models or DEMs. The AEC SVS receives external inputs from other aircraft systems such the Inertial Reference System (IRS), the Air Data Computer (ADC), and the Global Positioning System (GPS), to determine aircraft state and position. This information is used to derive the proper terrain display, both through location and aircraft attitude. The ADS-B component receives position and intention information broadcast by other aircraft. Information concerning the relative location and altitude of the other aircraft is then displayed on the SVS display to further improve the pilot's situational awareness, especially with respect to traffic. The 3D-CDTI display will be enhanced by referencing traffic information to terrain. This will make it much easier for the flight crew to determine location of the traffic.

Integration of information from multiple data sources on either one display or a Multi-Function Display (MFD) is not a new concept and has recently been demonstrated in other systems such as SVS [2] and Capstone [3]. Because of its role in the proposed 3D-CDTI, the SVS system concept will be discussed in more detail in section II. Capstone is an Alaskan initiative originated from cooperation between the FAA and the Alaskan aviation community to improve safety of flight for General Aviation (GA) aircraft in Alaska [3]. In Capstone, ADS-B is combined with GPS and weather information as inputs to an MFD. A terrain awareness function furthermore provides the Capstone pilots with the necessary ground proximity information on their MFDs. The proposed 3D-CDTI differs from the Capstone system in the display of the traffic (via ADS-B) and terrain information on a perspective (3D) display format similar to the display format used in an SVS.

Section II discusses SVS as the basis on which the 3D-CDTI is built. Next, the 3D-CDTI architecture and its components are described in detail in Section III. Section IV focuses on the ADS-B aspect of the 3D-CDTI. Finally, the flight test setup onboard Ohio University's King Air flying laboratory and local flight test are discussed in Sections V and VI, respectively.

II. SYNTHETIC VISION SYSTEMS

Synthetic Vision Systems (SVS) may improve flight safety by increasing the pilots' situational awareness in low to near-zero visibility conditions to a level of awareness similar to daytime clear weather flying [4]. This is accomplished by providing the pilots with a depiction of the external environment, the so-called virtual visual environment. This depiction can be portrayed on a Head-Down Display (HDD) and/or a Head-Up Display (HUD) and provides aircraft state information (e.g. altitude, attitude, airspeed, etc.), guidance and navigation information, and a perspective depiction of the terrain as viewed "from the cockpit". Other types of information can also be presented such as traffic and weather. Note that the proposed 3D-

CDTI does add the traffic information component by integrating the SVS display with ADS-B. NASA's Aviation Safety Program has been investigating SVS as a mitigation strategy for accident categories such as Controlled Flight Into Terrain (CFIT), runway incursions, low visibility loss-of-control scenarios; and also to allow for advanced precision approach procedures [5].

Ohio University's SVS component is a non-certified research system that uses a DEM to present terrain information to the flight crew on a HDD [4]. This prototype has been developed under cooperative agreement with the NASA Langley Research Center. The SVS receives external inputs from other aircraft systems, such as an IRS, an ADC, and a Wide Area Augmentation System (WAAS) GPS receiver, to determine aircraft state and position. This information is then used to derive the proper terrain display, both through location and aircraft attitude.

III. 3D-CDTI ARCHITECTURE

Figure 1 shows a block diagram of the proposed 3D-CDTI architecture. The central 3D-CDTI processor receives data from the navigation aids (navaids) via an ARINC 429 interface and it receives traffic information via the ADS-B datalink. The processor then formats and passes the A/C state, position and traffic information to a graphics processor.

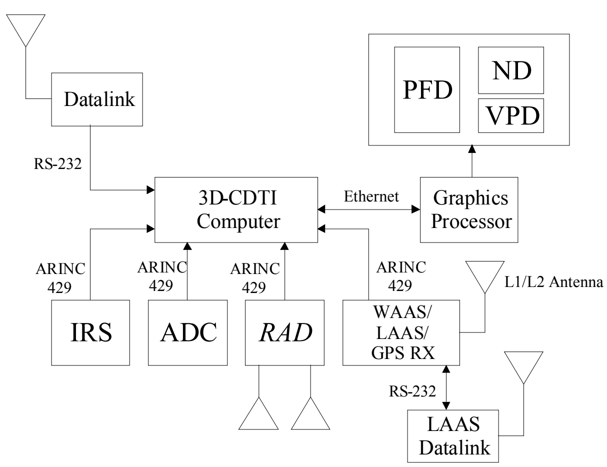

Figure 1. 3D-CDTI architecture.

Navigation Aids (navaids)

The following avionics systems are part of the current 3D-CDTI architecture and are used to determine the A/C state and position: an Inertial Reference System (IRS) providing pitch, roll, heading, track angle, ground-speed, and flight-path angle; an Air Data Computer (ADC) providing baro-altitude and true airspeed; and a Global Positioning System (GPS) receiver providing latitude, longitude (WGS '84) and altitude above mean Sea Level (MSL). In the current architecture, provisions are made to include a radar altimeter to obtain measurements of the altitude above ground level (AGL). Use of a radar altimeter supports a potential DEM integrity monitor function as described in [6]. This function would only be required if the terrain database integrity must be guaranteed with high levels of integrity. During the initial tests, no radar altimeter was utilized.

All navaid communications take place via an ARINC 429 bus. To enable ARINC communication, the 3D-CDTI computer is equipped with a Condor Engineering CEI-400 PC104 ARINC interface card. The following ARINC words are collected and processed:

Table 1. ARINC 429 words used the 3D-CDTI

	Label (octal)	Sensor
Pitch	324	IRS
Roll	325	IRS
True heading	314	IRS
Track Angle	313	IRS
Flight Path Angle	323	IRS
Ground Speed	312	IRS
Latitude	110	GPS
Latitude Fine	120	GPS
Longitude	111	GPS
Longitude Fine	121	GPS
Altitude (MSL)	076	GPS
UTC	125	GPS
UTC Fine	140	GPS
UTC Fine Fractions	141	GPS
Altitude	203	ADC
Altitude rate	212	ADC
True Airspeed	210	ADC
Indicated Airspeed	206	ADC
Baro corr. Altitude	204	ADC
Altitude (AGL)	056	RAD

Graphics Computer

The 3D-CDTI computer relays the A/C state and traffic information to the graphics or display processor. The display processor drives a 15" plat panel liquid crystal display that functions as an HDD. The display

Figure 2. DELPHINS display screenshot.

software (DELPHINS) was developed by Delft University of Technology and is used by Ohio University through a memorandum of agreement. Delft University's software is versatile and can be setup in various configurations.

The display configuration, selected for the flight tests, is a combination of a Primary Flight Display (PFD), a Navigation display (ND), and a Vertical Profile Display (VPD) [7]. Figure 2 shows a screenshot of the selected DELPHINS display configuration. The PFD provides an egocentric view and provides tactical information such as velocity, altitude, roll, heading, track, pitch, and flight path angle. In effect, the PFD consists of two layers; (1) a 3D object layer; (2) and a symbology layer. The terrain and traffic are depicted in the 3D object layer; the terrain is overlaid with a checkerboard texture pattern [7]; and the traffic is represented in the form of wire-frame aircraft as is illustrated in Figure 3.

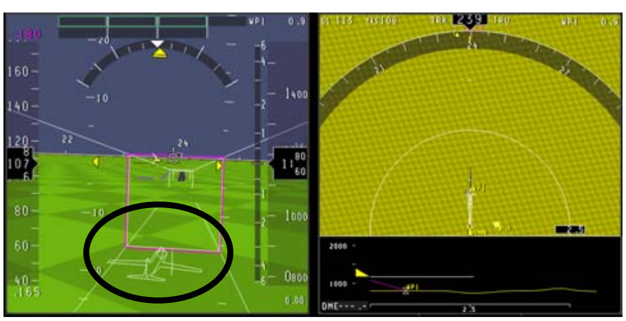

Figure 3. Wire-frame representation of traffic on the PFD

The ND shows a plan view providing the pilot with strategic information. Other traffic is visualized on the ND by symbology similar to TCAS symbology; diamonds are used to represent the aircraft; see Figure 4. The VPD shows the terrain profile along the airplane's planned track [8] providing the pilot with the necessary strategic information such his track with respect to the terrain.

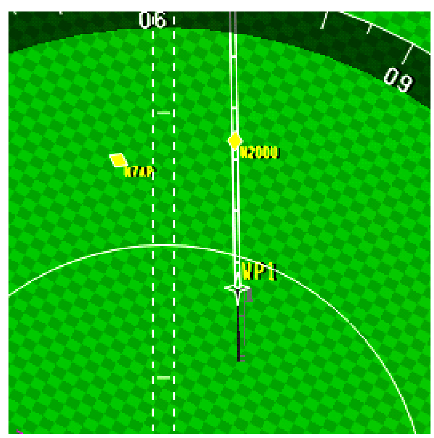

Figure 4. Traffic (N200U and 7AP) present on the ND.

Figure 2 shows an example of the PFD as flight tested in Southeast Ohio. Use of the PFD in the vicinity of UNI does not illustrate the display's 3D capabilities to its full extent due to the lower altitude of the hills in southeastern Ohio. A screenshot of the display in Colorado in the vicinity of Eagle-Vail (EGE) is included in Figure 5 to show the PFD's 3D capabilities.

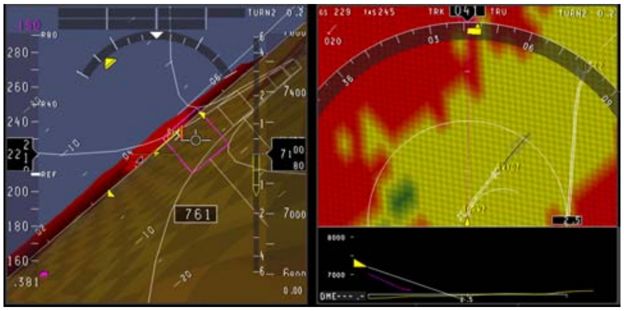

Figure 5. PFD in the vicinity of EGE.

GPS Receiver

The GPS receiver unit is a receiver-processor combination that supports both standalone GPS and WAAS. The receiver is furthermore capable of being used with Ohio University's prototype Local Area Augmentation System (LAAS). A block diagram of the receiver is shown in Figure 6.

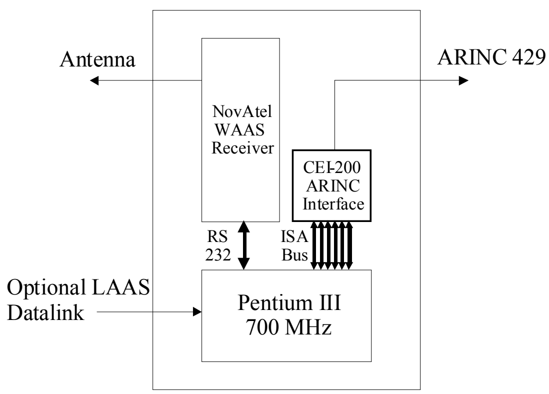

Figure 6. GPS receiver architecture.

A central processor unit communicates with a Novatel Euro4E-L1L2W WAAS receiver and generates the applicable ARINC 429 data words (see Table 1) at a rate of 5Hz; latitude, longitude, altitude MSL, and UTC time. To enable LAAS operation, a VHF Datalink (VDL) (or other LAAS datalink) receiver must be added to the setup and a LAAS ground station must be present. The software running on the processing unit already supports LAAS. For discussed flight tests WAAS accuracies were sufficient and no LAAS capability was utilized.

ADS/B

The FAA's Safe Flight 21 program is improving airborne situational awareness with the Automatic Dependent Surveillance-Broadcast (ADS-B) system. Each aircraft broadcasts its current position and intention to air traffic management systems on the ground and other nearby aircraft. This allows airborne flight crews to know the relative location and altitude of intruder aircraft thus improving the pilot's traffic awareness. In general, the position information is based on standalone GPS or differential GPS receiver outputs.

In the final 3D-CDTI prototype the UPS Aviation Technology (UPSAT) ADS-B system will be used as the preferred testbed. The UPSAT ADS-B system uses the Link Display Processor Unit (LDPU) to serve as a datalink manager from Mode-S, VHF Data Link Mode 4 (VDLM4), or Universal Access Transceiver (UAT) datalinks. The LDPU drives several different ports using different serial bus formats.

Figure 7. Ground system setup: ADS-B simulator.

For the initial 3D-CDTI flight tests the ADS-B component was simulated and no other aircraft were involved to provide ADS-B traffic. The trajectories of other aircraft were simulated on the ground and the ADS data was up-linked to the test aircraft. Due to an incomplete UAT setup and interface, a Freewave data radio was used for the datalink. The Freewave data radios are spread spectrum radios that transmit less than 1 Watt at 902-928 MHz, therefore not requiring a license. Both the test airplane and the ground system were equipped with a Freewave data radio. Figure 7 shows a picture of the ground system setup at the Ohio University airport (UNI).

FLIGHT TEST SETUP

The 3D-CDTI was installed in Ohio University's King Air C90 flying laboratory (see figure 8). Figure 9 and 10 show the HDD installation on the co-pilot side of the cockpit and a close-up of the HDD, respectively.

Figure 8. King Air C90 Flying Laboratory.

Figure 9. King Air HDD installation.

Figure 10. HDD close-up.

The 3D-CDTI computer, the graphics computer, the IRS, and the WAAS receiver are 19" rack-mounted in the back of the airplane. This is illustrated in Figure 11.

Figure 11. Equipment installation.

The 19" equipment rack also contains a Keyboard-Video-Monitor unit that is able to display a copy of the HDD to the passengers and the research engineer for demonstration and evaluation purposes.

INITIAL FLIGHT TEST RESULTS

Two flight tests were performed on February 19th, 2002 in the vicinity of UNI using Ohio University's King Air C90. The purpose of these flight tests was to flight check the navaids, the 3D-CDTI computer, and the HDD installation. Figures 12 and 13 show the horizontal flight profiles in terms of latitude versus longitude, whereas Figure 14 shows the vertical profile of both flights expressed in feet MSL.

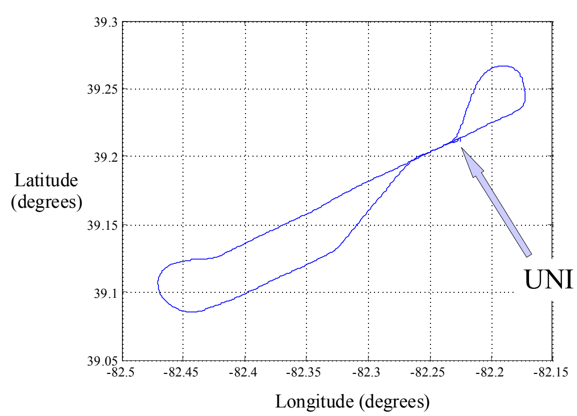

Figure 12. Horizontal flight profile; flight test #1.

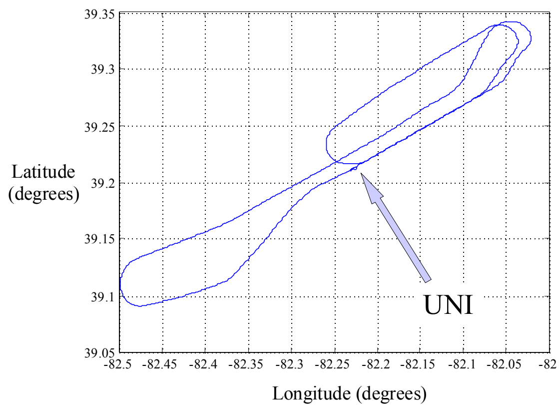

Figure 13. Horizontal flight profile; flight test #2.

All flight profiles were derived from position data from the Novatel WAAS receiver. Flight 1 consisted of two approaches: one to runway 7 and one to runway 25. Flight 2 consisted of two approaches to runway 25. Two intruder aircraft were simulated; N7AP on a standard ILS approach to runway 25; and N200U on course to runway 25 with heading 220.

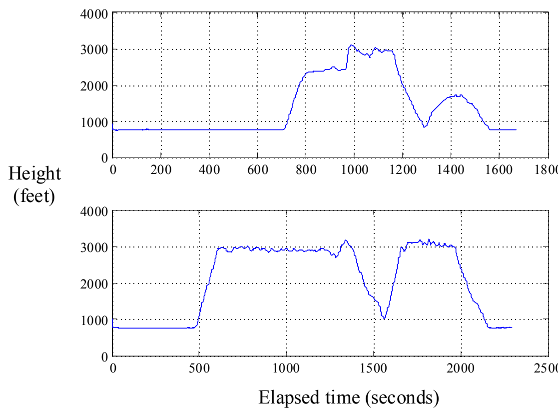

Figure 14 Vertical flight profiles (flight test #1 and #2).

During the flights, traffic and terrain were successfully displayed on the PFD, ND, and VPD. Two intruder aircraft were simulated in the ADS-B simulator. Figure 15 shows the approach to runway 25. A 3D perspective tunnel-in-the-sky [9] was added to both the PFD and the ND for approach guidance. The tunnel-in-the-sky follows a standard ILS approach to runway 25. Note that one of the intruder aircraft (N7AP) is on approach to runway 25. The color scheme on the ND is similar to the color scheme used in conventional Enhanced Ground Proximity Warning Systems (EGPWS); green represents terrain that is safely below the aircraft; yellow represents terrain that is within 1000ft AGL; and red is used for terrain with which collision with is imminent.

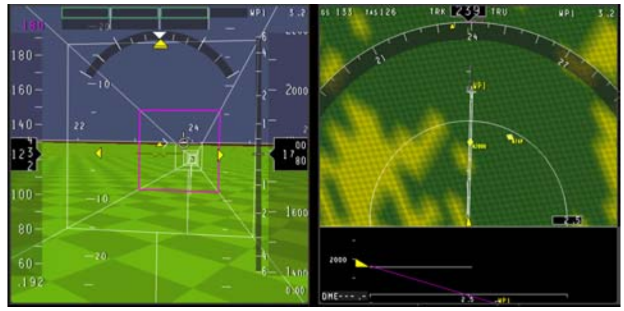

Figure 15. 3D tunnel-in-the-sky approach to rwy 25.

Figures 16 and 17 show two more snapshots of the display during the final approach and landing phases of the King Air. One can observe the change in color scheme from green to yellow to red as the airplane closes in on the terrain.

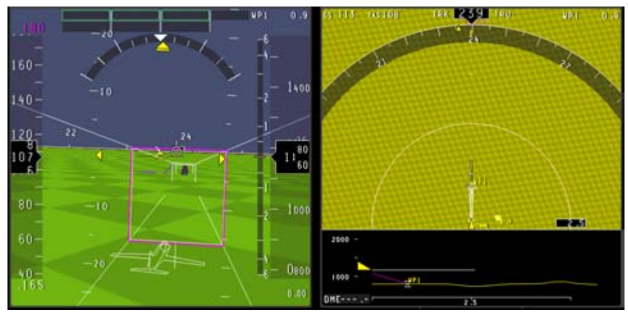

Figure 16. King Air final approach.

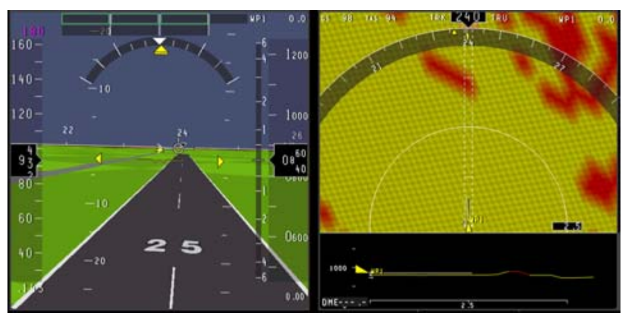

Figure 17. King Air landing.

Summary and Conclusions

A prototype three dimensional cockpit display of traffic information was successfully implemented and flight-tested on Ohio University's King Air C90 flying laboratory. The ADS-B component was simulated using a ground station and a datalink based on a Freewave data radio. The simulated traffic was successfully displayed in flight and updated on the pilot's PFD by wireframe aircraft and on the ND by diamonds and identifiers. Terrain based on DTED Level 0 terrain data and proximity indications were successfully depicted on the PFD, ND, and VPD.

FUTURE WORK

The next step is to complete the integration with the UPS Aviation Technology ADS-B system through interfacing with a UAT and flight test the final prototype. Switch scenarios between SVS and full 3D-CDTI capabilities will also be investigated. Finally, replacement of the IRS by a low-cost inertial measurement unit/ GPS receiver will be considered and flight-tested.

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