Abstract

Developed specifically for tactical military aircraft operations, TERPROM® is the world leading Digital Terrain System, offering a range of capabilities that can provide both safety and tactical benefits to the aircraft.

The system is an established and well-proven product that has been in production since 1991. To date it has been selected by fourteen Nations worldwide for use on numerous platforms. The number of military aircraft equipped with TERPROM® is now over 5000 and growing.

TERPROM® provides the following functions:

- Terrain Referenced Navigation (TRN)
- Predictive Ground Collision Avoidance System (PGCAS)
- Advanced Terrain Avoidance Cueing (ATAC)
- Obstruction and Wires Warning and Cueing (OWWC)
- Database Terrain Following (DBTF)
- Air to Ground Ranging Functions
- Terrain Awareness Display (TAD)

At the core of the system is the Terrain Referenced Navigation (TRN) capability which navigates by combining aircraft navigation data (e.g. inertial and, or GPS) and radar altimeter measurements of height above ground level (agl), with terrain heights alms from the stored map data, to produce a navigation solution referenced to the terrain map data. This navigation solution then allows the other TERPROM® functions to use the map data to provide their safety and tactical capabilities.

Three variants of TERPROM® have been developed to satisfy the airborne platform market:
- Fast Jet, Military Transport, Helicopter

TERPROM® is a living product that has and continues to receive significant internal investment to increase its capability, functionality and performance to support future opportunities. Current areas of development include:

- Use of higher resolution map data which will increase the performance of TERPROM® and offer enhanced capability to platforms flying nap of the earth, enhanced capability in urban areas and could also reduce any platform reliance on GPS.

- Integration with active forward looking sensors to provide additional information to the Navigation, Situational Awareness and Ranging functions and also to provide new capabilities such as real time mapping of unmapped terrain features and obstructions.

Introduction

TERPROM® is a Digital Terrain System (DTS) that is designed to increase the situational awareness of the aircrew, reduce the workload of the aircrew and provide protection against Controlled Flight Into Terrain (CFIT).

The development of TERPROM® began in the mid 1970s to support low level covert Terrain Following capa-
bilities for cruise missiles (Fig.1). In the early 1980s, the TERPROM® system was adapted for use on fixed wing military fast jets. During the adaptation for fast jet use, the primary focus of the system switched from Terrain Following to passive covert Predictive Ground Collision Avoidance. Following extensive flight testing with the United States Air Force (USAF), the first production contract for TERPROM® was let by the USAF in 1990 for the F-16 reserve fleet.

Development of the TERPROM® software has continued resulting in the selection of the system for a variety of military fixed wing platforms throughout the world. TERPROM® is currently in operation on all UK Royal Air Force (RAF) front line aircraft, the RAF Advanced Jet Trainer (AJT) and several USAF platforms (Fig.2).

In the mid 1990s, the development of TERPROM® TAWS, a variant of TERPROM® for use on military transport aircraft was started. The development of TERPROM® TAWS involved modifying the basic TERPROM system to account for the lower dynamic abilities of the transport aircraft and adding additional capabilities to meet the requirements of the commercial Technical Service Orders (TSOs).

In 1999, the first production TERPROM® TAWS program for the USAF C-17 aircraft was awarded. This was followed in 2003 with the selection of TERPROM® TAWS for the C-130 Avionics Modernization Program (AMP).

In the late 1990s, the development of a variant of TERPROM® for rotary wing aircraft was started. This development included adapting TERPROM® for slow speed operation, the addition of a lateral cueing capability and the integration of an active sensor to provide greater obstruction coverage while operating in Nap Of the Earth (NOE) conditions.

The number of military aircraft equipped with TERPROM® is now over 5000 and growing. To date TERPROM® has been selected by fourteen Nations worldwide for use on numerous platforms. The transport variant of TERPROM®, TERPROM® TAWS is in service with the USAF on the C-17 aircraft and has been selected as part of the C-130 AMP program.

**Terrain Referenced Navigation**

When generating alerts of impending CFIT, a key ingredient in the ability to produce accurate and timely alerts is a precise knowledge of the aircraft position with respect to the terrain. For systems that use a digital terrain database, there are two potential sources of error: the primary navigation source and the digital terrain database. This is shown graphically in Fig.3.

In Fig.3, the true aircraft position places the aircraft in close proximity to the true terrain. However, due to errors in the aircraft Inertial Navigation Unit (INS) the aircraft position as indicated by the INS provides an inaccurate representation of the aircraft proximity to the terrain. In addition, the mapping errors within the digital terrain database result in an error between the true terrain and the terrain as depicted by the digital terrain database.

The INS horizontal error is driven by the errors in the sensors (accelerometers and gyroscopes) and typically degrades over time. Even with a high grade military INS, the INS error can degrade by as much as 0.8 Nautical Miles per flight hour. The accuracy of the vertical channel of the INS is driven by the accuracy of the barometric altimeter which will drift over time due to changes in the atmospheric conditions. It is not unknown for the INS vertical channel to be in error by more than 100 feet. The accuracy of the terrain database information is dependant upon the collation method used in the generation of the database. It is not unusual for the database to have systemic surveying errors of up to 250m in the horizontal plane and 50m in the vertical plane.

If uncorrected INS and digital terrain data is used to generated potential CFIT alerts then there is a high probability of both missed and nuisance alerts due to the inherent errors in both sources. This leads to reduce pilot confidence in the system which ultimately results in the system becoming unusable.

Even if GPS data is used either as the navigation source, or to correct the inertial errors in the INS, the problem of nuisance and/or missed alert due to errors in the digital terrain database still exists.

To overcome the problem of INS errors and digital terrain database surveying errors, TERPROM® employs a Terrain Referenced Navigation (TRN) system. The purpose of TRN is to estimate the errors in both the INS and the terrain database and provide a highly accurate position
estimate relative to the digital terrain database. TRN operates by correlating the actual terrain profile overflown with the terrain information stored in the Terrain Database as shown in Fig.4.

The baro-inertial altitude from the INS provides an estimate of the instantaneous aircraft altitude Above Mean Sea Level (AMSL). The output from the radio altimeter (radalt) provides an estimate of the instantaneous aircraft height Above Ground Level (AGL). By differencing these two signals, an estimate of the elevation of the terrain beneath the aircraft can be obtained. By continually differencing the Baro-inertial altitude with the radalt height, a vertical profile of the terrain under the aircraft flight path can be produced. When this vertical profile is combined with the horizontal component of the flight path then a three dimensional terrain profile can be generated.

This terrain profile information is then fed into a multi state adaptive Kalman Filter contained within the TRN capability to find a corresponding terrain profile match within the Terrain Database. The correlation of the two terrain profiles (actual v terrain database) provides an estimate of the position registration errors between the INS and the Terrain Database. These position registration errors are then output by TRN as a set of corrections that can be applied to the INS to provide a highly accurate, drift free, navigation solution relative to the on-board terrain database.

If we refer to Fig.3 we can see the effect of applying the TRN corrections to the INS. With the TRN corrections applied to the INS, the INS is corrected for both the INS errors and the Database errors. This produces a TRN navigation solution which in absolute terms (relative to the true aircraft position) is incorrect, however in relative terms (relative to the terrain database) provides a navigation solution that indicates the same aircraft position relative to the true terrain. When providing terrain based functionality it is the relative accuracy of the navigation solution that is important rather than the absolute accuracy of the navigation solution.

Using a TRN solution, one-sigma horizontal accuracies of 10 - 25 meters and one-sigma vertical uncertainties of 1 - 5 meters (relative to the terrain database) are typical. Fig.5 shows the TRN accuracy for a typical low level flight profile. This level of terrain referenced accuracy is unobtainable without a TRN based navigation solution. It is this highly accurate terrain database relative navigation solution that permits TERPROM® to provide timely and reliable terrain database based functionality.

As described above, TRN operates by correlating the terrain profile overflown by the aircraft with the terrain information contained within the terrain database. The accuracy of the TRN solution is therefore, to a certain extent, dependent on the uniqueness of the terrain profile along the flight path as shown in Fig.6. When flying over rough terrain, the terrain profile is more unique resulting in an improved TRN accuracy. When flying over smooth terrain, the uniqueness of the terrain is reduced and would normally result in a reduction in the TRN accuracy.

To help reduce the negative effect of low terrain roughness on TRN, the adaptive Kalman Filter within TRN includes a model of the INS. Using consecutive terrain position error estimates the Kalman filter uses the INS model to estimates the INS sensors errors. Thus, when Radalt readings are unavailable (e.g., at high altitude, or high bank angles) or when the Radalt information provides no horizontal position information (e.g., over flat terrain or over water), the Kalman Filter propagates the INS sensor error estimates through its INS mode to update its INS position error estimates. The INS model within the TRN Kalman Filter allows a rapid estimation of the INS position and sensor error estimates when rugged terrain is encountered but means that the INS position error estimates degrade slowly when operating over flatter terrain.

The TRN Kalman Filter allows TERPROM® to maintain an accurate terrain relative navigation solution for several minutes even with prolonged absence of meaningful radio altimeter information. One of the other by-products of the Kalman Filter is the ability of the filter to provide a confidence level on its navigation solution. This confidence level is used by PGCAS and OW/C to optimize the area of terrain scanned by the capabilities.

The primary inputs to the TERPROM® TRN capability are INS data, radalt data and map data. As a result, the TERPROM® TRN capability has been designed to operate in the absence of GPS data. Therefore, although the primary purpose of the TRN capability is to provide an accurate navigation solution for the other database based capabilities within TERPROM®, the TRN capability can also be used to provide an accurate, drift free, navigation solution in scenarios where GPS may be unavailable or denied.
Predictive Ground Collision Avoidance

Using the accurate terrain referenced navigation solution provided by the TRN capability and the terrain information stored in the Terrain Database, the Predictive Ground Collision Avoidance System (PGCAS) capability is designed to provide an alert to the pilot if the aircraft flight path is determined to be dangerously close to the terrain.

First the PGCAS capability determines a scan area to define the terrain and obstructions ahead of the aircraft that need to be considered as potential threats to the aircraft. The shape of the scan area is based on the navigation accuracy, aircraft speed and turn rate.

The length of the scan area is proportional to the ground speed of the aircraft and ensures that the PGCAS capability is able to provide alerts for terrain up to 5000 ft above the current aircraft altitude. The width of the scan area is proportional to the navigation confidence figure provided by the TRN Kalman Filter. By using the TRN confidence figure, the width of the scan area is optimized for the navigation performance ensuring that no alerts are missed while minimizing nuisance alerts. When the TRN capability has a high confidence in its navigation solution, the PGCAS scan width will be small, thus reducing the possibility of nuisance alerts. If the confidence in the TRN navigation solution reduces, the width of the scan area will be increased to ensure that no alerts are missed.

During straight and level flight, the centre of the scan area is aligned with the horizontal flight path vector and the sides of the scan area are parallel to centerline of the scan area. However, if the aircraft is in turning flight, then the centre of the scan area is slewed into the turn by an angle that is proportional to the turn rate. The sides of the scan area are also flared out relative to the scan area centerline by an angle to allow for an increase or reduction in the current turn rate.

All the terrain and obstructions within the scan area are examined and used to create a Worst Case Profile (WCP). The WCP is a two dimensional terrain profile that is in effect the silhouette of the terrain and obstruction contained within the scan area (see Fig.7).

The WCP is then raised by the Minimum Clearance Height (MCH) that is the desired minimum clearance between the aircraft and the terrain and obstructions. The MCH can be set by the pilot to any value between 50 ft and 2000 ft. Having generated the WCP and the MCH, PGCAS alerts are calculated by comparing the WCP and MCH with an aircraft recovery maneuver projected from the current aircraft position and flight path angle (see Fig. 8). If the recovery maneuver intersects with the WCP raised by the MCH then a PGCAS alert is generated.

The PGCAS recovery maneuver replicates the expected pilot and aircraft response to a PGCAS alert and consists of five phases as follows:

- Phase I - Pilot Reaction Time
- Phase II - Roll to Wings Level
- Phase III - Onset of Aircraft Pull Up
- Phase IV - Constant g Pull Up
- Phase V - Climb Out at Constant Climb Angle

By using an aircraft recovery maneuver, PGCAS alerts are based on a "Time To React" that takes account of the aircraft attitude, the aircraft dynamic capabilities and the relative height of the terrain and/or obstruction to be cleared. Simpler predictive systems, and reactive systems, that are based on "Time to Impact" take no account of the height of the terrain to be cleared and are prone to nuisance or missed alerts.

Each of the parameters within the PGCAS recovery maneuver can be updated in real time during the flight. This ensures that the PGCAS recovery maneuver accurately reflects the current aircraft capabilities thereby minimizing nuisance alerts. This allows PGCAS to use a less aggressive recovery maneuver when the aircraft climb capability is reduced e.g. slow speed, higher altitude, external stores loaded or under an engine out condition.

Advanced Terrain Avoidance Cueing

The PGCAS capability described above provides alerts of impending Controlled Flight Into Terrain. The expected response to a PGCAS warning is a severe pull up maneuver. For some application, primarily rotary wing aircraft, a pull up recovery maneuver may not be the most appropriate maneuver. For these applications, the Advanced Terrain Avoidance Cueing (ATAC) capability has been developed to provide the pilot with additional situational awareness information regarding the terrain either side of the aircraft to enable to pilot to determine if a more appropriate evasive maneuver is available.
ATAC is an enhancement to the PGCAS capability that includes two additional scan areas, one to the left of the PGCAS scan area and one to the right of the PGCAS scan area. For each of the scan areas, ATAC generates a Worst Case Profile for the terrain and obstructions and then determines the flight path angle required to clear each Worst Case Profile by the MCH (Fig. 10). ATAC then provide cues related to the three flight path angles for display on a Head Down Display or Head Up Display. Armed with this information the pilot can then determine if a lateral recovery maneuver is more appropriate than a vertical recovery maneuver.

Obstacle and Wires Warning Cueing

As mentioned earlier, the anticipated response to a PGCAS warning is the execution of an immediate pull-up maneuver. However, for obstructions or wire e.g. power lines, if the pilot has full aware of the situation it may be more advantageous for the pilot to execute a turn command to avoid the obstruction rather than a climb maneuver.

The Obstacle and Wires Warning and Cueing (OWWC) capability is designed to increase the pilot’s situational awareness by providing pre-cursor alerts of man-made obstructions and wires prior to the generation of a PGCAS warning. These pre-cursor alerts enable the pilot to locate man made obstructions visually, assess their threat to the aircraft and determine if it is more appropriate to fly around them rather than fly up and over. If the pilot chooses to ignore the OWWC alert then a PGCAS alert will continue to be generated at the time at which the pilot is required to initiate the pull-up maneuver to clear the obstruction.

Similar to the PGCAS capability, the OWWC capability scans the obstruction database to determine all the obstruction that may potentially lie in the aircraft flight path as shown in Fig. 9.

The scan area used by OWWC is similar to the scan area used by PGCAS capability and uses the same alignment and width. The length of the scan area is shorter than the PGCAS scan area but still allows OWWC alerts to be provided up to 20 seconds before the aircraft reaches the obstruction. Unlike the PGCAS scan area, the sides of OWWC the scan area are always flared irrespective of the aircraft turn rate. By permanently flaring out the sides of the scan area, the OWWC scan area will always detect obstructions either side of the aircraft in addition to obstructions directly ahead of the aircraft.

For each of the obstructions within the scan area, the OWWC capability compares the vertical component of the current aircraft flight path with the elevation of the obstruction. If the aircraft flight path does not clear the obstruction by at least the MCH used by the PGCAS capability then an OWWC alert is generated.

By using the aircraft flight vector rather than a recovery maneuver, OWWC alerts will be generated earlier than PGCAS alerts (Fig. 11). This ensures that the pilot has time to identify the obstruction and take alternative evasive action thus preventing the generation of a PGCAS alert.

If the OWWC capability detects an obstruction that meets the criteria for the generation of an OWWC alert, the capability determines if the obstruction position is to the left of the aircraft flight path, to the right of the aircraft flight path or along the aircraft flight path. The OWWC capability will then issue either an "Obstruction Left", "Obstruction Right" or "Obstruction Ahead" audible alert as appropriate. The generation of a directional OWC alert helps to reduce the field of view that pilot needs to consider when visually detecting the obstruction.

If the OWWC capability determines that an OWWC alert is required, the OWWC capability also determines if the obstruction causing the alert is a single point obstruction or a connected obstruction. The OWWC capability provides separate alerts for single point obstructions and connected obstructions.

Terrain Awareness Display

The TERPROM® PGCAS and OWWC capabilities provide alerts of situations that require aircrew reaction. These capabilities are particularly useful for aircraft operating at low level where a momentary loss of situational awareness may place the aircraft in a hazardous situation. However, when operating at medium to high altitudes, no alerts should be generated by the TERPROM®. In this situation, these alerts are only generated because the aircrew have lost situational awareness and have inadvertently deviated from the pre-planned flight route.

To assist the pilot in maintaining situational awareness, and thereby preventing CFIT alerts, TERPROM® can produce a Situational Awareness Display that shows a plan view of the terrain surrounding the aircraft. Using
the terrain and obstruction databases, the Terrain Awareness Display (TAD) capability determines the altitude of the terrain and obstruction for each pixel position within the selected display range. The TAD capability then sets the color of each pixel based on the difference between the terrain elevation at the pixel position and the current aircraft altitude as shown in Fig.12.

Typically, terrain that is more than 2000 ft beneath the aircraft will not be displayed (i.e. will appear black on the display), terrain between 2000 ft beneath the aircraft and the current aircraft altitude will be displayed in varying shades of green, terrain between the current aircraft altitude and 2000 ft above the aircraft will be displayed in shades of yellow and terrain more than 2000 ft above the aircraft will be shown in a shade of red. In the event that a PGCAS alert is generated, TERPROM® places a box on the display over the terrain that is responsible for the generation of the PGCAS alert.

The relative elevations used for color determination can be updated in real time during the flight allowing the color band definitions to be changed for different phases of operation e.g. Tactical / Non-Tactical.

Figure 13 shows an example of a terrain display produced by TERPROM®. By displaying the elevation of the terrain relative to the current aircraft altitude, it is easy to determine if the terrain is above or below the aircraft and the relative severity of the terrain.

Database Terrain Following (DBTF)

Although a major role of TERPROM® is to enhance the safety of the aircraft during low level operation, due to the accurate terrain referenced navigation solution and knowledge of the terrain surrounding the aircraft, TERPROM® can also provide additional functions to increase the mission effectiveness of the platform.

One of these functions is the Database Terrain Following (DBTF) capability. The DBTF capability is designed to provide vertical steering cues to enable the pilot to maintain a fixed clearance between the aircraft and the terrain.

The DBTF capability uses the same scan area and thus the same WCP as the PGCAS capability. Using the same WCP for both PGCAS and DBTF ensure consistency between the DBTF steering commands and the PGCAS alerts. This ensures that no PGCAS alerts are generated if the pilot correctly follows the DBTF steering commands.

Similar to the PGCAS capability, the WCP is raised by the Minimum Separation Distance (MSD). The DBTF capability uses the MSD rather than the PGCAS MCH to prevent nuisance PGCAS alerts from being generated if the pilot deviates marginally from the DBTF steering command. The PGCAS MCH would normally be set to approximately 75% of the DBTF MSD.

The DBTF capability then uses the WCP and MSD to create a flyable profile (Fig.14). The flyable profile is a two dimensional profile that is designed to follow the WCP and MSD as close as possible but within aircraft pitch and vertical acceleration limits.

Once the DBTF capability has created the flyable profile, it then determines the vertical acceleration required for the aircraft to follow the flyable profile (the G command). The difference between the G command and the current aircraft vertical acceleration is used to produce a TF steering command that is displayed on the Head Up Display (HUD) as a rectangular box (Fig.15).

Unlike Terrain Following Radars (TFRs), the TERPROM® DBTF capability is passive in nature and has no forward emissions. In addition, the DBTF capability has other benefits over the TFR when flying over ridges. The TFR requires line of sight to the terrain and this means that as the aircraft approaches a ridge, the TFR cannot see the terrain behind the ridge. For safety reasons, the TFR has to assume that the terrain behind the ridge is at the same elevation as the ridge. As a result, the TFR will command the aircraft to cross the ridge with a zero vertical velocity and a zero vertical acceleration. As the aircraft crosses the ridge the TFR will realize that the terrain elevation reduces beyond the ridge and will start to command the aircraft to descend. However, this latency in generating a negative vertical velocity command means that the aircraft will exceed the desired clearance height on the far side of the ridge.

The TERPROM® DBTF capability does not have this line of sight restriction and therefore knows before the aircraft reaches the ridge that the terrain elevation reduces beyond the ridge. This allows the DBTF capability to command the aircraft to cross the ridge also with a zero vertical velocity, but with a negative vertical acceleration.
This allows the aircraft to more closely follow the terrain on the far side of the ridge.

**Air to Ground Ranging**

The accurate terrain referenced navigation solution and the knowledge of the terrain surrounding the aircraft also allows TERPROM to provide air to ground ranging functions to increase the effectiveness of the platform (Fig.16).

The primary purpose of the Air to Ground ranging functions is to support weapon delivery systems on military aircraft, however the ranging functions can also be used to determine terrain information to support other capabilities.

The Air to Ground Ranging capabilities use the accurate navigation solution provided by TRN together with the knowledge of the terrain around the aircraft provided by the Terrain Data Base to provide three passive, accurate ranging functions:

- Line Of Sight Ranging (LOSR)
- Horizontal Ranging (HR)
- Co-ordinate Ranging (CR)

**Horizontal Ranging (HR)**

The HR capability supports the engagement of Targets at a known position relative to the aircraft. The HR capability receives a horizontal offset from the current aircraft position and using the TRN navigation position, the HR capability calculates the HR position within the digital terrain database and returns the terrain elevation at this point.

Typically HR is integrated with dumb bomb fall line calculations as shown in Fig.17. The Fire Control Computer (FCC) uses a flat earth approximation to determine an initial horizontal range to a bomb fall line impact point. This range is then fed into the HR capability which returns the elevation of the terrain at the impact point. The elevation is then used in the next iteration of the bomb fall line. This loop can then be iterated at a high rate (typically 12.5 to 25 Hz) allowing the bomb fall line calculations to continuously account for the terrain ahead of the aircraft.

In mechanizations where HR is integrated with the dumb bomb fall line calculation the Continuously Computed Impact Point (CCIP) marker (Fig.18) that is displayed on the Head Up Display (HUD) to support the dropping of bombs can be seen to track the terrain ahead of the aircraft regardless of the ruggedness of the terrain. The improvement in the accuracy of the CCIP using TERPROM®'s HR capability significantly improves the accuracy of weapon delivery when operating over undulating terrain.

**Line of Sight Ranging (LOSR)**

The LOSR capability is designed to support the engagement of targets of opportunity. Unlike the HR capability, the LOSR capability receives a line of sight (LOS) from the aircraft to a target. The LOSR capability then determines where the LOS intersects with the terrain in the map database and returns the position of the intersection and the X, Y and Z ranges from the aircraft position to the position of the intersection. LOSR then returns the target location, elevation and the 3d range. This information can then be fed into targeting pods, handed off to other aircraft or fed into dumb bomb fall line calculations.

The LOSR capability is typically integrated on to aircraft with Helmet Mounted Sights and/or Laser Designators. With the integration of the LOSR capability the time taken to lock the designator onto the target can be substantially reduced, thus reducing aircrew workload and time over the target and in turn increasing the likelihood of mission success and survivability.

**Co-ordinate Ranging (CR)**

The CR capability is designed to support the engagement of pre-planned targets or targets of opportunity handed off by other aircraft. The CR capability receives the geographic position of a target and returns the elevation and range to the target. In addition, if the target position is close to the aircraft (within 20 km), the CR capability also indicates if a direct line of sight exists to the target. The determination if a direct line of sight exists can be used to determine the aircraft obscuration status with respect to a ground based threat.

**Recent TERPROM® Developments**

The Sections above describe the basic TERPROM® functionality already in service. The current performance and functionality within TERPROM® is limited by the available hardware resources: Processing Power, Processing Memory and Storage Capacity. Over time, the hard-
ware resources available to TERPROM® are increasing which allows improved TERPROM® performance and/or new functionality to be developed.

The following sections describe some of the TERPROM® enhancements currently under development that will utilize the increase in hardware resources now available.

**Map Enhancements**

The map data used by TERPROM® is Digital Terrain Elevation Data (DTED) supplied by local government agencies such as the National Geospatial-Intelligence Agency (NGA). The DTED data represents the terrain data as a series of points on a regular grid pattern. The DTED data has five different Levels with each Level representing a different grid spacing as shown in Fig. 19.

All fast jet and military transport variants of TERPROM® use DTED Level 1 data which has a grid spacing of approximately 100m. The selection of DTED Level 1 data has historically been driven by the limited non-volatile storage capacity available to TERPROM® and by the limited availability of DTED Level 2 to 5 data.

In recent years, the non-volatile storage capacity available to TERPROM® has increased dramatically and many mapping agencies are now producing DTED Level 2, 3, 4 and 5 data which has opened up the possibility of using these higher levels of DTED within TERPROM®. The use of higher level DTED within TERPROM® will provide a more accurate representation of the terrain which is expected to improve the performance of TRN.

Initial studies performed with DTED Level 2 and DTED Level 4 data have shown improvement in the TRN positional accuracy, but more importantly have shown a significant improvement in the TRN uncertainty. Flights that resulted in a 30m uncertainty with DTED Level 1 data were returning a 10m uncertainty when DTED Level 4 data was used. The improved TRN uncertainty will lead to a reduction in the width of the PGCAS scan area which will further reduce the potential for nuisance alerts allowing the aircraft to operate at even lower altitudes.

In addition to the direct improvements brought about by the improved TRN accuracy and uncertainty, the greater terrain fidelity achievable by the higher levels of DTED will increase the fidelity of the PGCAS and ranging solutions within TERPROM®, particularly when the aircraft is operating over extremely rugged terrain.

Further TERPROM® work is planned on the use to higher levels of DTED to determine what additional functionality can be provided by TERPROM® now that the higher levels of DTED are becoming available.

**Active Sensor Integration**

The PGCAS capability within TERPROM® uses a terrain and obstruction database to determine if a collision is imminent. The quality and content of the obstruction databases is not as good as the terrain databases. In particular, low level obstructions and power lines are not always fully mapped. This does not tend to be a problem for fixed wing operation, however, for rotary wing Nap Of the Earth (NOE) operation, this present a potential significant threat.

In recent studies it has been identified that 70% of the US Military rotary wing collisions with obstructions involved obstructions that were mapped. These collisions could have been prevented by a purely passive TERPROM® system. However, the remaining 30% of the collisions involved obstructions that were not mapped and therefore could not have been prevented with the basic passive TERPROM® PGCAS capability described earlier.

To help overcome the problem with unmapped obstructions, TERPROM® has been integrated with a Laser Obstacle Detector (LOD). The LOD scans ahead of the aircraft and picks up all obstructions within its field of view. The LOD and TERPROM® are complementary systems; each system offsets the limitations of the other system. The LOD is particularly good at detecting wires that may be missing from the obstruction database, however the LOD requires line of sight to the obstruction and therefore cannot look over hills. TERPROM® has no line of sight restriction, however its knowledge of obstructions is limited to the obstruction contained within its obstruction database.

TERPROM® blends the LOD information with the digital terrain and obstruction to produce a terrain and obstruction profile that is more robust than each individual input as shown in Fig. 20. The result of the LOD integration is a more robust PGCAS solution particularly for NOE operation.
The concept of TERPROM® integration with a LOD has already been proven during a number of flight trials with the UK Army, however the current maturity of LODs does not yet make this system practical for production.

Dynamic Map Building

In addition to the basic LOD integration described above, Atlantic Inertial Systems is continuing to develop more sophisticated integrations techniques with LODs. These techniques include a dynamic map building capability that remembers any unmapped obstructions identified by the LOD. These unmapped obstructions are then available at any time during the flight, even when they are no longer within the field of view for the LOD. The unmapped obstructions can also be passed to other aircraft in the operational area through a secure data link and can also be used post flight to update the obstruction database.

As with the active sensor integration, the concept of dynamic map building has demonstrated during flight trails in the UK, however the current maturity of LODs does not yet make this system practical for production.

Additional Development

In addition to the two specific TERPROM® development activities identified above, Atlantic Inertial Systems is continuously improving the TERPROM® product. Some of the additional TERPROM® improvement currently under development include:

- The development of a TERPROM® Line Replaceable Unit (LRU) that combine the TERPROM® product with a Data Loading / Data Recording facility.
- The development of Helicopter Power Management capability to support helicopter operation over high terrain.
- The development of a Helicopter Low Visibility Landing capability to overcome the problem associated with "Brown Out" during landings in temporary landing sites.
- The development of Collaborative Navigation capability to allow several aircraft to share sensor and TERPROM® information via a secure data link to improve the overall accuracy and performance TERPROM®.

Conclusion

TERPROM® is a proven product with a pedigree built up across a number of platforms and aircraft type that increases the platforms survivability and effectiveness and reduces crew workload.

TERPROM® is continuously being developed to satisfy emerging customer requirements and to fully utilize the advancements in hardware resource availability.
Fig. 4 Terrain referenced navigation

Fig. 5 Typical TRN performance

Fig. 6 TRN performance against Terrain roughness

Fig. 7 Worst case profile

Fig. 8 PGCAS recovery maneuver