

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Optimization of NOE Flights Sensors and Their Integration

Tamilselvam Nallusamy and Prasanalakshmi Balaji

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.86139>

Abstract

This chapter unveils an enhancement strategy for nap-of-the-earth. The nap-of-the-earth (NOE) mode is the most energizing, most unsafe, and is generally the slowest. Military aircraft to maintain a strategic distance from opponent detection and assault in a high-thread circumstance use it. NOE used to limit discovery by the ground-based radar, targets and the control system. The radar altimeter (RA) or terrain following radar (TFR), terrain awareness and warning system (TAWS) used to identify the curbs during flying in NOE flights. Here, while the plane is at the nap of the earth activity, the speed and the height must be moderate as effectively decided. The terrain following radar (TFR) keeps up the altitude from the beginning. Therefore, we analyze the issue to expand the performance of the airplane by extending the terrain by a few modes of the TAWS, which given by various aviation authorities¹. Further to this, different TAWS modes of action, explanation of mode selection and progression in TAWS clarified in detail. This chapter displays the MATLAB programme for a few patterns of TAWS mission, and simulation of the flight path for the excessive terrain closure rate from mode two operation of the flight.

Keywords: nap-of-the-earth, radar system, MATLAB programming, terrain awareness and warning system

1. Introduction

Nap-of-the-earth (NOE) is a very low-altitude flight route utilized by military plane to keep away from enemy detection and assault in the high-threat environment. This mode is the slowest

¹International civil aviation organization (ICAO), United Kingdom civil aviation (UKCA), civil aviation authority (CAA) and federal aviation authority (FAA)

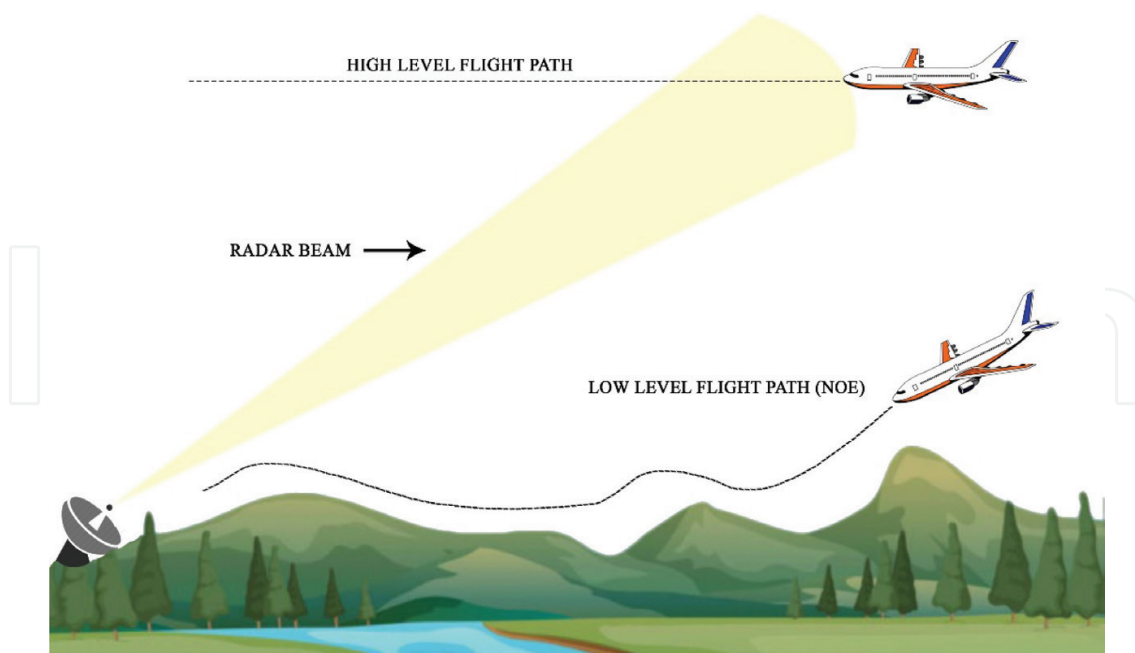


Figure 1. Nap-of-the-earth flight.

but exciting. When flying at the nap of the earth, the pilot flies at varying airspeed, altitude, and remains as close to the earth's floor as feasible. Geographical functions used during NOE flight, and this keeps below enemy radar coverage [1]. NOE used to reduce detection through an antagonistic plane, ground-based radar, or onslaught targets. Doppler radar can decide NOE flight, but the aircraft that comes closer to has to be inside radar range within the first area, and low flight minimizes this opportunity because of the impact of terrain protecting [2].

The lowest NOE flying is by helicopters because they have lower speeds and more maneuverability than fixed-wing aircraft, mainly in the fast-jets. Only helicopters can fly at treetop levels or even below height of surrounding trees where there are clear areas (such as in river gullies), flying under wires (such as electricity cables). Attack helicopters can hide behind trees or buildings, popping up just enough to use their (rotor mast-mounted) radar or other sensors and then minimally exposing themselves to launch weapons. Then further NOE flying can make the escape [2].

Figure 1 represents the nap of the earth operation. In this, the high-level route and the low-degree route of the flight served. The high-level path identified by using the radar device from the base, while the low-level flight direction used to fly below the radar. They have their flight course, which avoids the collision with terrain.

2. Sensors in NOE flights

In most case, pilots perform the NOE operation in daylight hours using visual reference. The commonly used navigation systems are:

1. Radar altimeter.
2. Terrain-following radar system.
3. Terrain awareness and warning system.

In this chapter, TAWS modes given by the ICAO analyzed. The global positioning system (GPS) also helps to find the exact position of the flight from the decision height (DH).

3. Obstacle detection and analysis

There are two types of obstacle detection in NOE flights:

1. Detection using active sensors.
2. Detection using passive sensors.

3.1. Obstacle detection using passive sensors

A passive sensor is a microwave device developed to collect and measure natural emissions produced by components of the earth's surface and its ecosystem [2, 3]. The passive sensor measures the output as a combination of environmental temperature, surface roughness, surface composition, and other physical properties. The measurements of passive sensors determined with the help of molecular resonance by fixing the radio frequency bands. These frequencies no longer alternate and statistics could not duplicate in other frequency bands. The passive sensors could able to detect low-quality emissions particularly very sensitive multitude emissions on the ground both from the frequency band wherein measurements made and from out-of-band. Spaceborne passive sensors offer the capacity to acquire all-climate, day and night, worldwide observations of the earth and its environment [2, 3].

3.2. Obstacle detection using active sensors

An active sensor measures the signals that reflected, refracted or scattered from the earth's surface or its atmosphere. Spaceborne active sensors worked on the radar principle and used in many applications related to atmosphereology, meteorology [2]. For example, Doppler radar analyses the electromagnetic echo from a moving object and define the absolute velocity of the object; mapping radars use synthetic aperture radar to scan the sizeable geographical area for geography. There are some specific radar systems to identify the human density in the forest as well as the construction area by measuring the reflective waves. Navigation radars commonly employed in ships for collision avoidance and it works by sensing reflections. Spaceborne active sensors used in the meteorological-satellite communication services. Sensor frequency allocations recurrently shared with supplementary radar systems; as such, systems frequently well matched with the operation of the sensors [2, 3].

4. Radar altimeter

The radio altimeter does not depend on radar standards beyond the way that it reacts to reflected signs. The radio altimeter used to show targets roughly around 300 miles. The time gap between the transmitted and received signals analyzed by radar altimeter and that determined the distance between the destinations. A radio altimeter communicates an FM tweaked continuous wave 4 GHz signal. Their frequency balanced on “entrance ramp” with the goal that it changes direction. The spectrum between the transmitted and received signals ceaselessly analyzed to show altitude above the terrain [2, 4]. The radio altimeter does not depend on radar standards beyond the way that it reacts to reflected signs. It used to show targets roughly 300 miles. The time gap between the transmitted and received signals analyzed by radar altimeter and determined the distance between the destinations. A radio altimeter communicates an FM tweaked continuous wave 4 GHz signal. Their frequency balanced on “entrance ramp” with the goal that it changes direction. The spectrum between the transmitted and received messages ceaselessly analyzed to show altitude above the terrain radar altimeter essentially projected to display the target locations within 2500 feet. It is inactive when the aircraft fly above 2500 feet [2]. A typical radio altimeter system on an airplane utilizes two antennas namely transmitting and receiving antenna. The transmitting and receiving antennas arranged as close to the point of the hinge as could expect under the circumstances, generally under the fuselage between the wings. Positioning and installation of the antenna in flight vehicle is very critical and harsh work. The antenna should never be situated at the nose or tail because the angle of attack could then contribute genuine mistakes [2, 5]. Low altitude flying airplanes use radio altimeter technology for escaping from ground radar detection. This technology is very famous in military based flying vehicles like helicopters. Terrain-following radar also uses this technology for allowing a plane to fly at high speeds over varied topography [1].

4.1. Working principle and applications

Radar altimeter works on one of the two methods. They are,

1. pulse modulated radar and
2. frequency modulated continuous wave FMCW radar.

4.1.1. Pulse modulated radar

Pulse modulated radar consists of a series of discrete pulsed radiation. In this method, the distance between the targets identified by analyzing the reflected transmitted radio waves.

4.1.2. Frequency modulated continuous wave (FM-CW) radar

Frequency modulated continuous wave radar (FM-CW) is capable of determining distance and is a short-range measuring radar set. This increases the reliability of the system. When

more than one reflected wave arrives at the radar antenna, providing distance measurement along with speed measurement is essential for identification. This kind of radar used to measure the exact height during the landing procedure of aircraft. It also used as early-warning radar and proximity sensors. The difference in frequency between that received from the ground and that transmitted is a measure of the time delay [2, 6, 7].

4.2. Applications of radar altimeter

4.2.1. Civil applications of radar altimeter

Radar altimeters frequently used by business aircraft for landing, particularly in low-visibility situations and in automatic landings by enabling the autopilot to sense when to begin the flare maneuver. Radar altimeters transfer information to the autothrottle. Above ground level (AGL), radar altimeters commonly give interpretations up to 2.5 K feet (760 m). The automatic landing capability of today's airplanes enhanced by installing at least one or usually several radar altimeters. Concorde and the British Aircraft Corporation BAC, 1-11 were equipped with radar altimeters even though they are old aircraft. In the present day, some of the smaller airplanes in a sub-50 seater category like jet stream series and ATR 42 are using radar altimeter [2, 6, 7].

4.2.2. Military applications

Military airplane utilizes radar altimeters to fly relatively very nearer to ground and the ocean to avoid radar detection. These radar altimeters are very much useful while targeting anti-aircraft weapons or surface-to-air missiles. Radar altimeter also used in terrain following radar. TFR allows fighter-bombers to fly at very low altitudes through radar altimeter system. In the advanced combat aircrafts, forward terrain looking radars used [6, 7].

5. Terrain following radar

Terrain-following radar is an aviation innovation that permits an extremely low-flying airplane to keep up a moderately constant height over the ground level. It dependent on TAWS and called as ground-hugging or terrain-hugging flight. It is like a GPWS. Record the general objectives of a TFR system in two classifications. The first of these would be to minimize detection by the opponent; subsequently, it is a vital factor or else the mission will fall flat if the aircraft identified. TFR provides active radar avoidance by increasing the terrain mask, lowering the altitude, lowering the RF signature, escaping or reducing the time in threat coverage and operation at night and adverse weather condition [4, 8, 9].

Minimizing detection is of no use if the flight crash inbound or outbound on the mission. Therefore, the other primary goal of a TFR is to offer maximum flight safety. Flight safety maximization achieved by maintaining safe altitude from terrain, avoiding unpredicted obstacles, consistent performance of the system, high availability/reliability [4, 8, 9].

The major goals of terrain following radar represented in **Figure 2**, the risk vs. terrain average clearance plotted in the graphical form. It helps us to determine the total risk value. This total

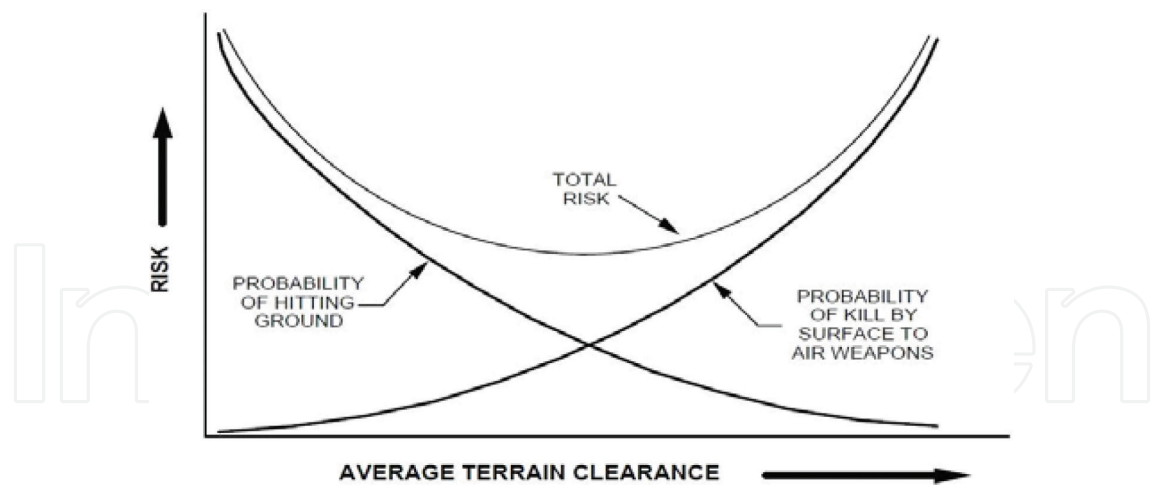


Figure 2. Terrain following radar vs. risk [4].

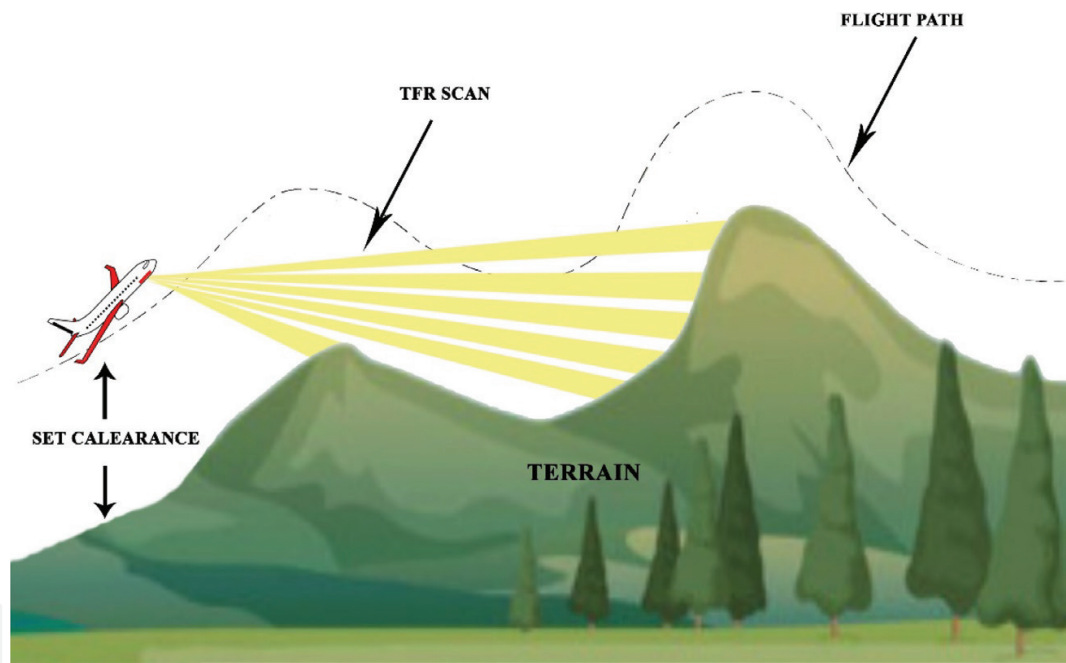


Figure 3. Terrain following radar scan.

risk obtained by the ground hitting probability and the probability of kill by the weapons, which varies in the order with risk and terrain clearance plot [4, 8, 9].

5.1. Scanning of terrain following radar

Terrain following radar scans the air gap in front of aircraft with a vertical scan. It produces a wedge of information in vertical, horizontal and azimuth direction. TFR scan the plane by referring horizon as the middle and provide the wedge above, below, left side, right side facet. All wedge patterns were interpreted and analyzed. An antenna scan pattern to produce this wedge illustrated in Figure 3.

5.2. Algorithm of terrain following radar

There have been several approaches to the terrain-following algorithms. The typical algorithm of terrain following radar is shown in **Figure 4a–d** which represents the following algorithms. They are,

1. template algorithm,
2. angle algorithm,
3. advanced low altitude algorithm, and
4. path following algorithm.

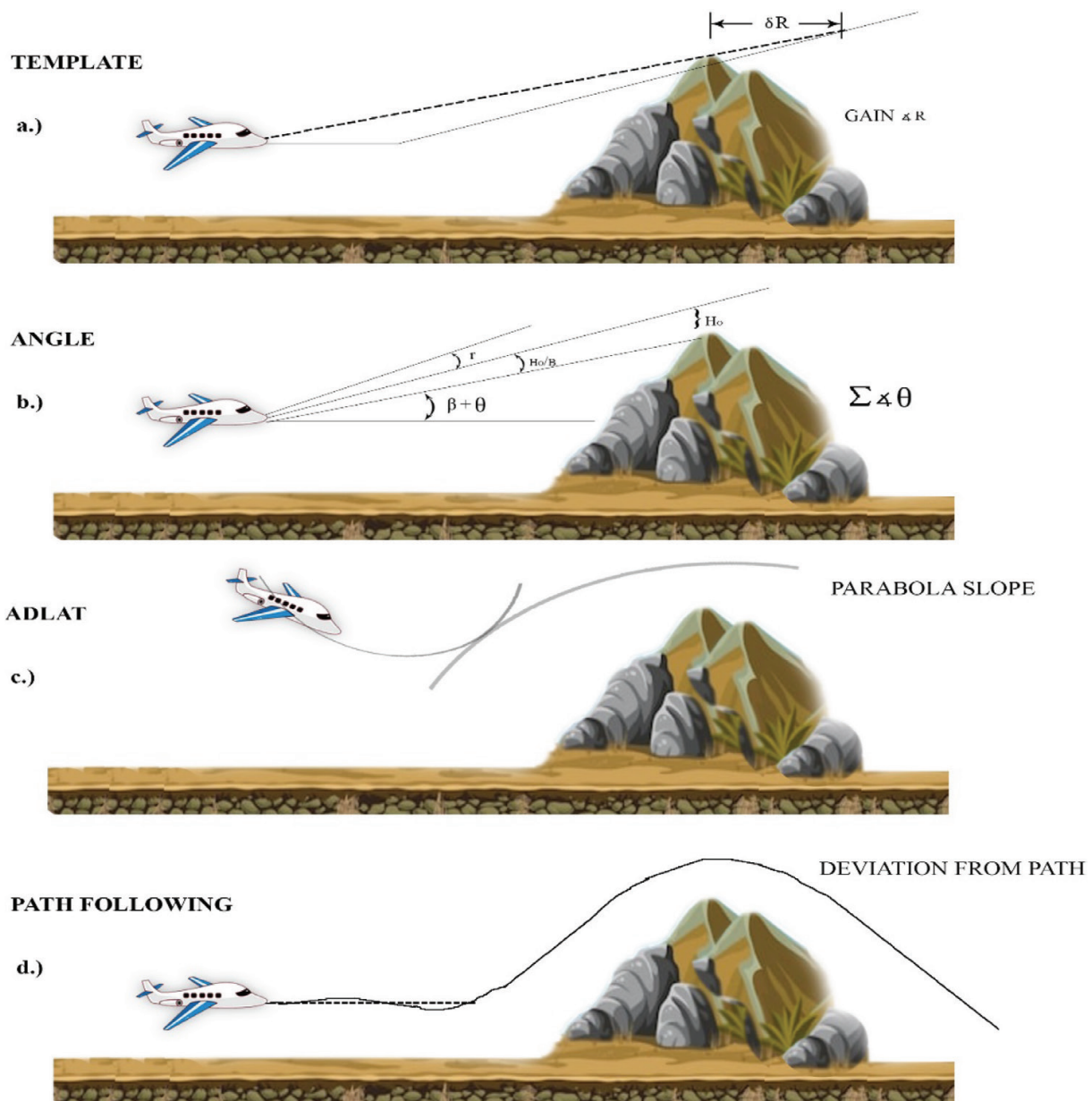


Figure 4. (a, b, c, and d) Terrain following radar computation approaches.

5.2.1. Template algorithm

Template algorithm creates two virtual lines in front of the aircraft in the airspace. These virtual lines form two sections; the upper one is decided based on the pitch up maneuvering of the airplane, whereas the lower part anticipated the set clearance. The terrains monitored as the radar scans the airspace in front of the aircraft. The return signals collected and processed for storing range and angle to the region. A pull up command generated when the terrain or other object crosses the template line. On the other hand, when the terrain clears the template line, a pulldown command generated. This full down command, bring the aircraft to original set clearance decided by the pilot [4]. This system implemented using analog processing prior to the advent of digital circuitry. **Figure 4a** shows the template algorithm.

5.2.2. Angle algorithm

Angle algorithm is the advanced version of template algorithm because it developed from the template algorithm. Similar to the template algorithm, the lower line set as the desired set clearance of the aircraft. Angle algorithm uses some of the angles, which displayed in **Figure 4b**. For clear understanding, one should know about the following terms:

- β —antenna scan angle
- θ —pitch angle of the aircraft
- H_o —desired set clearance
- R —range to the point of interest
- Γ —margin factor to allow for the pushover point at the peak of the climb not to drop below the set clearance.

When these angles combined, one will get the perspective to the object. For smaller angles, the total angle can be approximated by H_o/R . The margin factor tuned to the response of the aircraft. Further development in angle algorithm carried out, but coverage range minimized [4, 8, 9].

5.2.3. Advanced low altitude algorithm

Advanced low altitude or ADLAT algorithm developed at the start of the digital computation age. The concept of the ADLAT algorithm is to construct a parabola where the derivative taken to give a zero slope at the peak of the climb at the desired set clearance. Computation of this algorithm processed through individual terrain points and consistently updated as the airplane approaches maximum. To solve parabolic flight path related calculations, ADLAT algorithm uses square root functions and complex formulae. **Figure 4c** shows the probable flight path developed through parabolic derivative. From **Figure 4c**, it is clear that the offset terrain path defines the set clearance. Flying over a terrain, aircraft tend to surpass the preferred set clearance because aircraft could not make direct flight direction changes and equal the offset path [4, 8, 9].

5.2.4. Path following algorithm

Path-following algorithm is an advanced concept than all other algorithms because it requires significant computation power. In this method, a path developed by the flight when moving over terrain with the offset being the set clearance. Path-following algorithm generates flight path by tracking and correcting the offsets as the plane travels over the region. The path-following algorithm shown in **Figure 4d** [4, 8, 9].

6. Terrain awareness and warning system

Terrain awareness and warning system (TAWS) is a piece of airborne safety equipment designed to provide a warning on terrain collision to the pilot reliably and automatically [10]. Ground proximity warning system (GPWS) is the universally accepted system and developed from TAWS [15, 16].

TAWS provides proper warning about the upcoming obstacles and terrains by using terrain database and GPS positioning. Since TAWS depend on terrain database and GPS positioning, it gives a prediction based upon projected location and aircraft location. The system warns pilots by providing both voice and visual intimations. The pilot takes action according to the warning received from TAWS [11, 12]. The system is time-dependent, and therefore it reimburses the performance of aircraft and speed. TAWS and GPWS are not same because TAWS produces warning signals based on the aircraft's real position (indicated by built-in GPS) concerning a terrain map installed in the equipment whereas GPWS produces warnings only through the inputs received from the radio altimeter [15, 16].

TAWS works by using the instrumental values (like inbuilt GPS) and digital elevation data of the aircraft to know the future position, which interconnects the ground. So the pilot intimated through audio warning and visual warning about the upcoming terrain well in advance. **Figure 5** shows the typical TAWS (right side). The image, which displayed in the left side, shows different colors for the respective altitude rate from sea level by reference altitude [10–12].

6.1. There are mainly three classes in the terrain awareness and warning system

They are TAWS class A, TAWS class B and TAWS class C.

TAWS Class A provides the following features:

- Forward looking terrain avoidance (FLTA) by taking account of terrain, aircraft to generate alerts of both ahead and below the reduced terrain clearance and warnings of the terrain impact.
- A terrain awareness display, which shows terrain above the aircraft current altitude and up to 2000 feet below it, which can provide proactive situational awareness as well as safety net, functions.

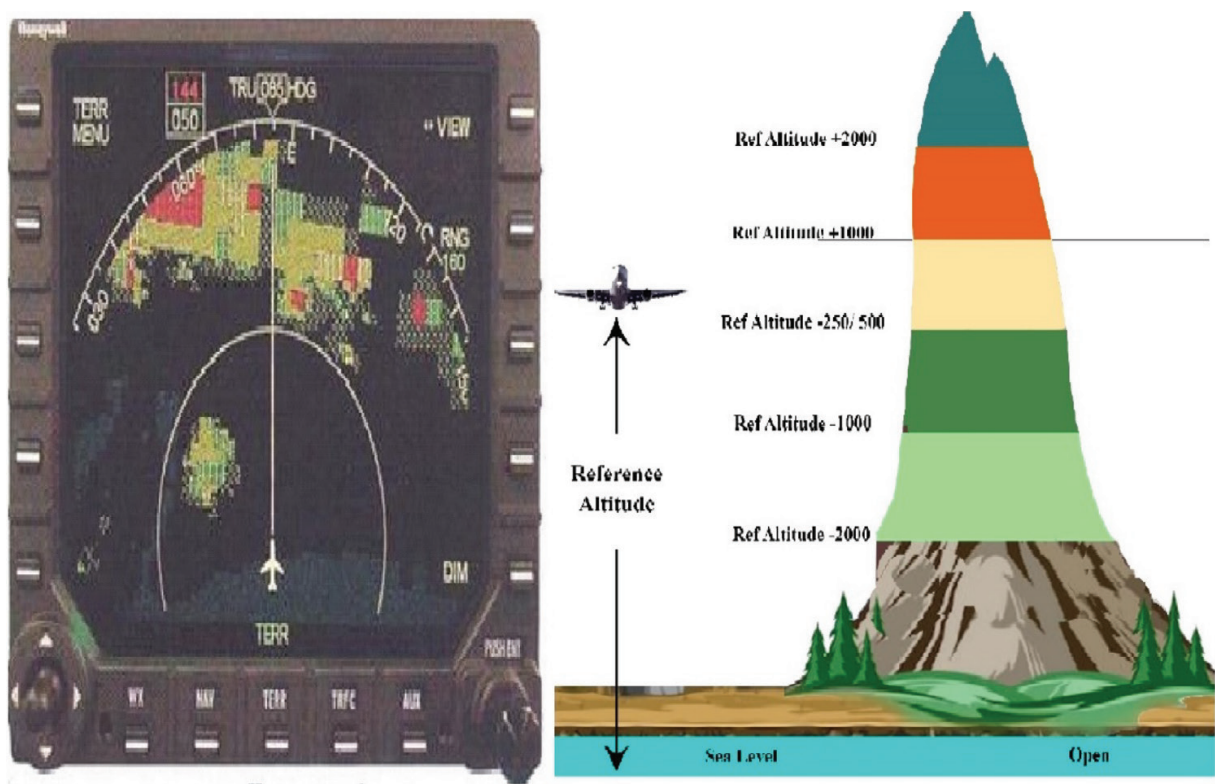


Figure 5. Terrain awareness and warning system.

- Basic GPWS functions—modes 1–6 using radio altimeter input moderated by aircraft position in relation to database terrain and obstacles (note that the mode 6 requirement is altitude voice call out(s).
- Premature descent alerting (PDA) if the aircraft descends below a normal approach path for the nearest runway.

TAWS Class B equipment provides the following:

- Forward looking terrain avoidance by taking account of terrain, the aircraft to generate alerts of reduced terrain both ahead of and below clearance and warnings of terrain impact.
- Basic GPWS modes 1, 3 and 6 only (there is no radio altimeter input).
- Premature descent alerting if the aircraft descends below a normal approach path for the nearest runway.

6.2. Modes of operation

The various sets of hazardous conditions that the GPWS monitors and provides alerts for commonly referred to as modes. These described in detail in the following paragraphs. Hazard awareness provided by TAWS aural alerts or warnings and illumination of alert and warning lights in response to different situations. **Table 1** shown below illustrates a typical TAWS system mode of the operation of flight, respectively.

6.3. Response to a TAWS activation

TAWS is a safety system, which provides two different warning when aircraft approaches terrain namely soft warning and hard warning. Soft warning indicates an unusual status with respect to terrain location that needs immediate attention and a change in aircraft configuration or flight path. On the other hand, hard warning indicates an unsafe situation, which needs immediate action. TAWS response procedures appropriately designed by operator based on the flight type and performance [13, 14].

6.4. Problem description

MATLAB program for the TAWS mode and its descriptions presented in this chapter. The “Excessive terrain closure rate” determination for **mode 2** programmed and simulated. The program created by using altitude-measuring formula by considering arbitrary pressure values for the various altitude

$$Z = \left(\frac{-RT}{gM} \right) \ln P_0 - \ln P \quad (1)$$

where Z—height from the ground, RT—gas constant temperature, g—gravity, P_0 —random pressure value, P—sea level pressure, respectively.

The ultimate aim of the program is to fly the aircraft in the well-defined path without collision. For example, for the mode operation set the “z” value for some extent. When it detects some obstacles, i.e., in excessive terrain closure rate, it will show “TERRAINTERRAIN” “PULL UP” message and when it comes to normal steady flight shows “NO WARNING” message.

Mode	Condition	Aural alert	Aural warning
1	Excessive descent rate	“SINKRATE”	“PULL UP”
2	Excessive terrain closure rate	“TERRAIN TERRAIN”	“PULL UP”
3	Excessive attitude loss after take-off or go around	“DON’T SINK”	(NO WARNING)
4a	Unsafe terrain clearance while gear not locked down	“TOO LOW GEAR”	“TOO LOW TERRAIN”
4b	Unsafe terrain clearance while landing flap not selected	“TOO LOW FLAP”	“TOO LOW TERRAIN”
4c	Terrain rising faster than aircraft after take off	“TOO LOW TERRAIN”	(NO WARNING)
5	Excessive descent below ILS glideslope	“GLIDESLOPE”	“GLIDESLOPE”(1)
6a	Advisory callout of radio height	(for example) “ONE THOUSAND”	(NO WARNING)
6b	Advisory callout of bank angle	“BANK ANGLE”	(NO WARNING)
7	Wind shear protection	“WINDSHEAR”	(NO WARNING)
NOT MODE NUMBERED	Terrain proximity	“CAUTION TERRAIN”	“TERRAIN TERRAIN PULL UP”

Table 1. The modes of operation in TAWS [17].

6.5. MATLAB programming

6.5.1. Program for mode 2 “Excessive terrain closure rate”

Here, at the mode 2 operation, if the “z” value more than 2500 feet, the display will show “NO WARNING” message. When the height drops 2500 feet and below, TAWS will show TERRAIN message and if reduced to 1500 feet, PULL UP message will show.

INPUT DATA

```
clear all; clc;
%% Definition of input pressure
P = 1e3.*[75.232 70 60 50 65 75 80 76 60 65 70 75 80 84 89 80 76 70 65 60 55]'; %% Initialization
of other required parameters
Rsp = 287; %(J/(kg /(kg K)) specific gas constant for air
T = 298; %( kelvin) assuming constant temperature throughout altitude Pnot = 101.325e3;
%(Pa) sea-level pressure
g = 9.81 ;%( ms^-2) acceleration due to gravity %z(size(P))=[];
% %Calculation of height and display of message for i = 1: size (P)
z(i) = (Rsp*T/g)*log(Pnot/P(i));
if (z(i) >= 2500) disp('NO WARNING') elseif (z(i) >= 1500) disp('TERRAIN') else
disp('PULL UP') end
end
%%Note
%z = 2500 corresponds to P = 75.232 kPa %z = 1 500corresponds to P = 84.748 kPa %z = 0000
corresponds to P = 101.325 kPa
```

6.5.2. Program for the simulation of excessive closure rate

In this simulation of excessive closure rate, we are going to simulate the aircraft moving on its path without collision with the terrain using the terrain awareness and warning system (mode 2) as per the regulation. The mode 2 warns flight crew of excessive closure rates with the rapidly rising terrain. If terrain rises significantly within 2000 feet of the aircraft, the terrain closure rate is measured. Up to this stage the “NO WARNING” message is displayed and when the aircraft reaches the maximum closure value at the higher threat condition the “TERRAIN TERRAIN PULL UP” message is displayed. And when the aircraft passes the terrain it came to normal low level fight and then “NO WARNING” message is shown.

INPUT DATA

```
%#control animation speed DELAY =0.1;num =1000; num1=500 %# create data x =linspace(-
pi,pi,num); c =linspace(-4,-pi,num1) e =linspace(pi,6,num1) y=(sin(x+1.5))
```

```

s=(sin(x+1.5))+1.5d=zeros(1,num1) for k=1:num1 d(1,k) = 0.5
end
f=zeros(1,num1) for l=1:num1 f(1,l) = 0.5 end
%# plot graph
plot(x,y,x,s,c,d,e,f),xlabel('x'), ylabel('y'), title('Flight Path'),grid on %# create moving point +
coords text
hLine = line('XData',x(1), 'YData',s(1), 'Color','r', ...
'Marker','^', 'MarkerSize',15, 'LineWidth',2);
hTxt = text(x(1), s(1), sprintf('(%0.3f,%0.3f)',x(1),y(1)), ...
'Color','r', 'FontSize',10, ...
'HorizontalAlignment','left', 'VerticalAlignment','top');
hLine1 = line('XData',c(1), 'YData',d(1), 'Color','r', ...
'Marker','^', 'MarkerSize',15, 'LineWidth',2);
hTxt1 = text(c(1), d(1), sprintf('(%0.3f,%0.3f)',c(1),d(1)), ...
'Color','r', 'FontSize',10, ...
'HorizontalAlignment','left', 'VerticalAlignment','top');
hLine2 = line('XData',e(1), 'YData',f(1), 'Color','r', ...
'Marker','^', 'MarkerSize',15, 'LineWidth',2);
hTxt2 = text(e(1), f(1), sprintf('(%0.3f,%0.3f)',e(1),f(1)), ...
'Color','r', 'FontSize',10, ...
'HorizontalAlignment','left', 'VerticalAlignment','top');
for j=1:length(c)
disp('WARNING!! TERRAIN TERRAIN PULL UP!!') set(hLine1, 'XData',c(j), 'YData',d(j))
set(hTxt1, 'Position',[c(j) d(j)], ...
'String',sprintf('(%0.3f,%0.3f)',[c(j)d(j)]) drawnow
j= rem(j+1,num1)+1;
if ~ishandle(hLine), end end
fori=1:length(x) set(hLine, 'XData',x(i), 'YData',s(i)) set(hTxt, 'Position',[x(i) s(i)], ...
'String',sprintf('(%0.3f,%0.3f)',[x(i) s(i)]))
drawnow
i = rem(i+1,num)+1; if ~ishandle(hLine), end end

```

```

for n=1:length(e) disp('NO WARNING')
set(hLine2, 'XData',e(n), 'YData',f(n)) set(hTxt2, 'Position',[e(n) f(n)], ...
'String',sprintf('(%0.3f,%0.3f)',[e(n) f(n)])) draw now
n= rem(n+1,num1)+1; if ~ishandle(hLine2),
end end

```

7. Conclusion

This chapter presented the optimization method for nap-of-the-earth flight operation using the sensors. In the nap of the earth operation, if we took in to the deep look, the use of terrain awareness and warning system has drastically decreased the collision with ground or the obstacles, which occurred while on controlled flight. However, with the advanced technological improvements and modern equipment, the accidents of collision are still happening.

The establishment of new systems and improving the existing ones may lead to prevent the accidents while flying at nap of the earth operation or at the low-level flying. Hence, the proper training to the pilot is mandatory to fly at the low altitude level with using the advanced equipment. Here in this project the terrain awareness and warning system taken for the safe flight operation. Further to this, different TAWS modes of operation and the explanation of mode selection in TAWS explained in detail. The MATLAB programming done for one mode of TAWS operation, the simulation of flight path for the excessive terrain closure rate from the mode 2 operation of flight is determined, and the outputs gained for the nap of the earth flights.

Acknowledgements

The authors are grateful to Mangalore Institute of Technology and Engineering, Mangalore, India and King Khalid University, Abha, KSA.

Author details

Tamilselvam Nallusamy^{1*} and Prasanalakshmi Balaji²

*Address all correspondence to: selva.gte.research@gmail.com

1 Department of Aeronautical Engineering, Mangalore Institute of Technology and Engineering, Mangalore, Karnataka, India

2 Department of Computer Science, King Khalid University, Abha, KSA

References

- [1] Anon. Helicopters at War (Blitz Editions). 1st ed. UK: Bookmart Ltd; 1996. ISBN-9781856053457
- [2] Tamilselvam N, Divya Priya D, Rajeswari B, Siddika N. Navigation systems. Noe flight sensors and their integration. *ARPN Journal of Engineering and Applied Sciences*. 2016;**11**(2):1285-1292. Available from: http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0116_3493.pdf
- [3] Thuy M. NASA Directorates. What are Passive and Active Sensors? National Aeronautics and Space Administration; 2012. Available from: https://www.nasa.gov/directorates/heo/scan/communications/outreach/funfacts/txt_passive_active.html [Accessed: 2017]
- [4] IEEE. Proceedings of the IEEE 1979 National Aerospace and Electronics Conference NAECON 1979; Part III, 1979; New York, NY, USA 1979. pp. 1089-1096. Available from: <http://www.theatlas.org/index.php?...a-history-of-terrain-following-radar>
- [5] Bhanu B, Das S, Roberts B, Duncan D. System for Obstacle Detection During Rotorcraft Low Altitude Flight. July 1996. Available from: <http://www.researchgate.net/publication/3002633> [Accessed: August 1996] DOI: 10.1109/7.532250A
- [6] Jim L. Types of radar. Improved forms of radar. In: Frequency Modulated Continuous Wave Radar. Scotland: University of St. Andrews. 2001. Available from: https://www.st-andrews.ac.uk/~www_pa/Scots_Guide/RadCom/part15/page2.html [Accessed: 2019]
- [7] Ahmad B. Radar/Radio 2013 Flight Instruments & Radio Navigational Aids-Radar/Radio Altimeter. 2013. Available from: http://www.slideshare.net/sajid93/radar-altimeter-assignment?Next_slideshow=1 [Accessed: November 2013]
- [8] Starling RJ, Stewart CM. The development of terrain following radar. *Aircraft Engineering & Aerospace Technology Journal*. 1971;**43**(4):13-15. DOI: 10.1108/eb034756
- [9] Krachmalnick FM, Vetsch GJ, Wendl MJ. Automatic flight control system for automatic terrain following. *Journal of Aircraft*. 1968;**5**(2):168-175. DOI: 10.2514/3.43925
- [10] Paul N. Terrain Awareness and Warning Systems—TAWS. Pilots Guide. 2005. Available from: <https://www.skybrary.aero/bookshelf/books/2328.pdf>
- [11] Duncan Aviation. Straight Talk About TAWS (Terrain Avoidance and Warning System). 2002. Available from: www.duncanaviation.aero/files/straighttalk/Straight_Talk-TAWS.pdf
- [12] Technical Standard Order—Terrain Avoidance and Warning System. 2002. Available from: <http://www51.honeywell.com/aero/common/.../TSOC151bPaper.pdf>
- [13] EASA. CS-ETSO/Amendment 2-Change Information. 2005. Available from: https://easa.europa.eu/system/files/dfu/NPA_14_2005.pdf
- [14] Federal Aviation Administration. 14 CFR Parts 91, 121, 135. 1995. Available from: http://www.faa.gov/documentlibrary/media/Advisory_Circular/AC_23-18.pdf [Accessed: 17 December 2002]

- [15] Terrain Awareness and Warning System Modes of Operation. 2014. Available from: http://www.skybrary.aero/index.php/Terrain_Avoidance_and_Warning_System_%28TAWS%29
- [16] United Kingdom Civil Aviation Authority. Ground Proximity Warning Systems. Specification No. 14. Issue: 2. 1976. Available from: www.caa.co.uk/docs/33/CASPEC14.PDF [Accessed: September 2002]
- [17] [https://skybrary.aero/index.php/Terrain_Avoidance_and_Warning_System_\(TAWS\)](https://skybrary.aero/index.php/Terrain_Avoidance_and_Warning_System_(TAWS)), 2014