DGLR Report 92-02

Deutsche Gesellschaft für Luft- und Raumfahrt e.V.
Forschungsinstitut für Anthropotechnik der FGAN e.V.

Advanced Display Systems for Aircraft, Vehicles, and Process Control

K.-P. Gärtner (Editor)

34. Technical Committee Meeting
September 24 – 25, 1991
Munich
BMW AG

Functions and Presentation Based on Digital Terrain Data for Deployment Support of Aircraft

Uwe Rathmann

1 Introduction

Digital terrain data provide an excellent basis for functions – with our without visualization on a display – which enhance the deployment options for aircraft or, in special cases, make deployment possible in the first place. Digital terrain data make a relatively accurate elevation value available in real-time at any location of a deployment area. Although it is possible to also extract elevation information from conventional topographic maps (including digitized maps), linking to and further processing in a digital processor and combination with other data (e.g. aircraft control) is not possible in practice.

In addition, separating various information such as elevation data, vector data, item data, and suitable structuring makes it possible to design displays such as maps so that they only contain the information required for the respective situation; that is, it is possible to show or hide information and therefore optimally adapt the display to the current situation.

In addition to military applications, civil aviation uses are also possible. These could include the following:

- Search and rescue
- Disaster response
- Reconnaissance, exploration
- Improving aviation safety

The following overview (Illustration 1) shows a number of different functions that can be realized based on digital terrain data. A larger number of these were implemented and investigated in an experimental ESG study; a selection of them is presented below.

Tactical map functions and displays

- Map displays (topographic, aeronautical, relief)
- Altitude-dependent map displays
- Flight mission data overlay
- Section display
- IP insertion
- Visibility display
- Acquisition / threat display
- Reconnaissance image overlay

Aircraft control aids

3-D aerial section functions	Artificial visibility aids and visibility

- Ground proximity
- Takeoff and landing clearance
- Obstacle warning
- Terrain avoidance
- Terrain following
- Auto TF/TA/TA

- Artificial visibility aids
- Artificial visibility
- Visibility fusion
- "Look ahead" views

Mission planning	Air drops

- Precise 3-D flight planning
- Visibility / sensor visibility simulation
- Threat / loss analysis
- Cost analysis

- Optimal approach
- Optimal air release point
- Precision navigation relative to the target / altitude above target

Illustration 1: Functions based on digital terrain data

2 Maps and simple perspective displays

2.1 Geographic information

The elevation data (DTED - Digital Terrain Elevation Data) of the "Landshut Block" were used to demonstrate some of the application and display possibilities. It approximately covers the area of Lower Bavaria (north-east of Munich).

The lower left (south-west) corner of the 1° x 1° block has the geographic coordinates 48° latitude and 12° longitude.

The display of geographic vector data (DFAD/LOC - Digital Feature Analysis Data/Lines of Communication) was not included in any of the applications; only a few cities were marked as reference points (small yellow squares). Instead, the elevation information in particular was utilized for the various analyses and displays. A relief method was used during data processing in order to give the user an immediate impression of the terrain topology. The DFAD/LOC data describe the surface characteristics of the terrain and include vectors for streets, settlements, rail lines, etc. The display was also realized based on these data; however, they are not presented here.

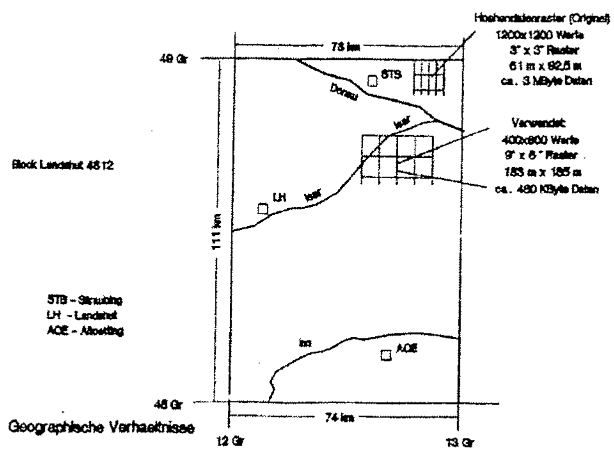
Block Landshut 4812 STB - Straubing LH - Landshut AOE - Altoetting Geographic Characteristics		Elevation grid (original) 1200 x 1200 values 3" x 3" grid 61 m x 92.5 m Approx. 3 MB data Used: 400 x 600 values 9" x 6" grid 183 m x 185 m Approx. 480 KB data

Illustration 2: Geographic characteristics of the Landshut block

2.2 Explanation of the colors and symbols

Illustration 3 shows an overall view of the Landshut block with relief characteristics and special color encoding. The following information applies to this and all following illustrations:

- Map orientation: North is at the top.

- Colors: Red, shades of brown, shades of green, aqua blue.
  The colors were assigned based on the assumed (e.g. for planning purposes) or actual operating altitude of an aircraft with an operational display.

  All elevations that are equal to or greater than the operating altitude are displayed in **red**; in this case, 500 m above sea level as can be seen on the color panel at the edge of the map.

  All elevations within a certain elevation range below the operating altitude are displayed in **brown**; in this case, 450 - 500 m above sea level. The elevation range settings can also be modified.

  All elevations below the brown elevation range are displayed in **green**.

The meaning of the colors for the pilot is as follows:

- Red areas represent a collision risk; they must be avoided under all circumstances.

- Brown identifies areas with critical elevations – in this case, up to 50 m below the planned or current operating altitude – where increased attentiveness is required since a collision is possible when falling below the operating altitude by even a small amount. In addition, it is important to consider that "features" such as forests or settlements can also be superimposed on top of the elevation data. Although these features can, in principle, be overlaid and considered in the analysis, this was not done here due to the insufficient processor and graphics resources on the PC used.

- On the other hand, it is possible to fly over all green areas without any risk since the safety distance is 50 m or more.

- **Yellow squares**: These identify the approximate location of settlements and are used for improved navigation. From top to bottom, the settlements are:

  - Straubing
  - Deggendorf
  - Pilsting
  - Landau

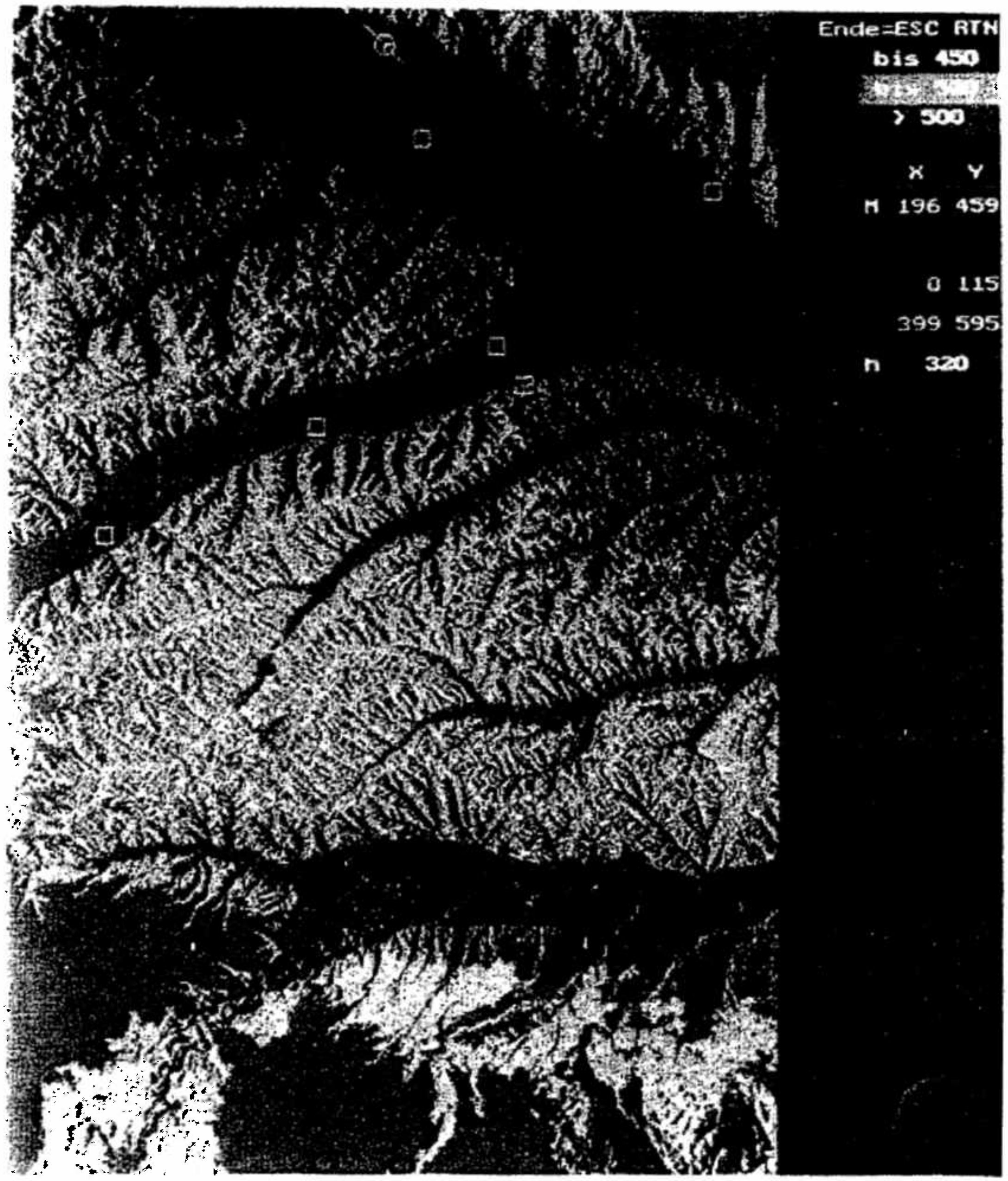


Illustration 3: Map display of the elevation data (DTED) of the "Landshut" block in relief format

- Dingolfing
- Landshut
- Vilsbiburg

- **Circle with 45° subsidiary lines:** This symbol at the upper edge of the display represents a target which is to be approached along the 45° subsidiary lines.

- **Cursor** in the shape of a small slanted arrow: The cursor is currently located in the target circle, but it can be moved to any location on the display. It is used to mark route points or read discrete elevation values.

- The **elevation function** is shown in this illustration. The elevation of the terrain for the respective cursor position can be viewed in the green field at the right-hand edge: h 320 [m]

2.3 Flight path creation and display

Illustration 4 shows a flight path with seven flight path points. It can be created interactively by moving the cursor and marking the route points on the map. Initially, a planned operating altitude – 450 m above sea level in this case – is assumed. In contrast to the prior illustration, a scale grid with distance information in km (can be switched to NM) has been activated for this map display.

The operating altitude-dependent color coding and the relief display make it easier to select the flight path and make terrain avoidance – using the terrain with a constant, low operating altitude – possible.

The illustration also shows the impact of changing the operating altitude from 450 m to 500 m (prior illustration). Compared to the prior illustration, there are now large areas that are red in color and cannot be flown across since the elevation of the terrain in these areas is ≥ to the operating altitude.

Part of the segment between flight path point 1 and flight path point 2 is in the brown elevation area. Therefore, a more detailed analysis of the elevations and the safety distance is required (see section 2.4).

The flight path creation function can be used during the flight planning phase and also during the flight. The generated 3-dimensional flight path position data are saved, and previously saved data can be read and displayed.

Illustration 4: Establishing a flight path and flight path points; constant operating altitude of 450 m above sea level

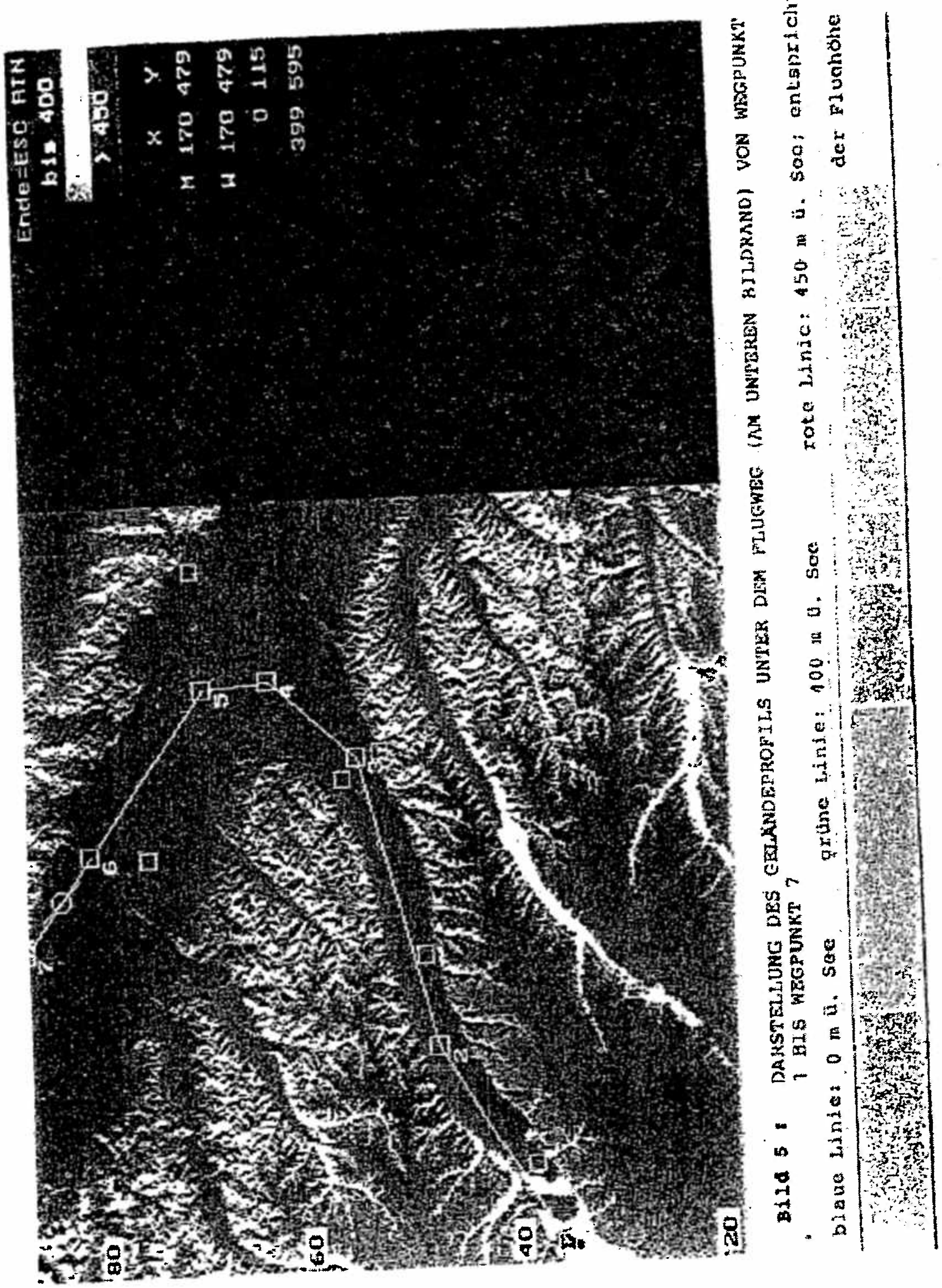


Illustration 5: Terrain display underneath the flight path (at the lower edge of the display) from flight path point 1 to flight path point 7

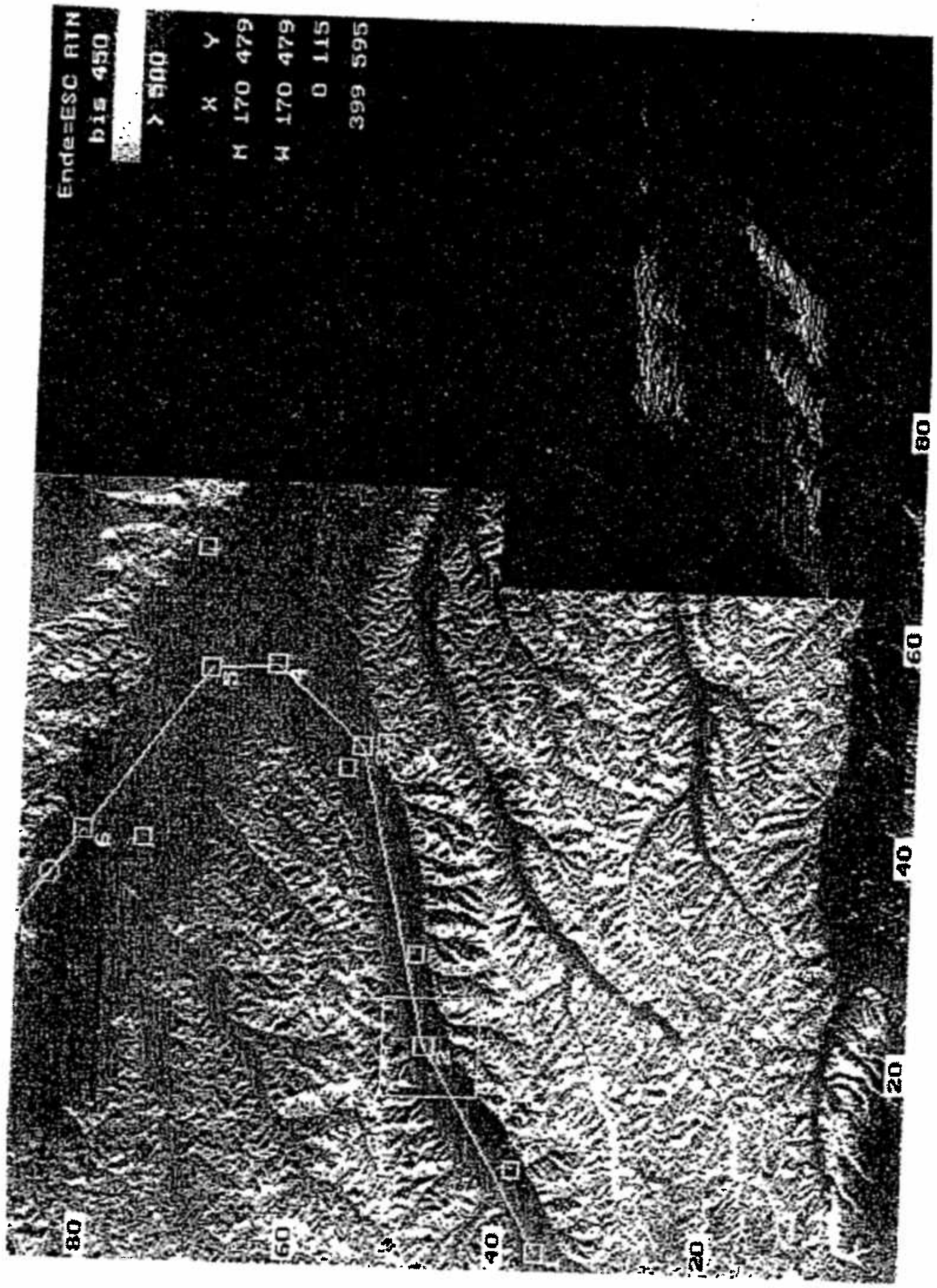


Illustration 6: Simple perspective display “cavalier display” of the section around flight path point 2 – Line of sight from S to N

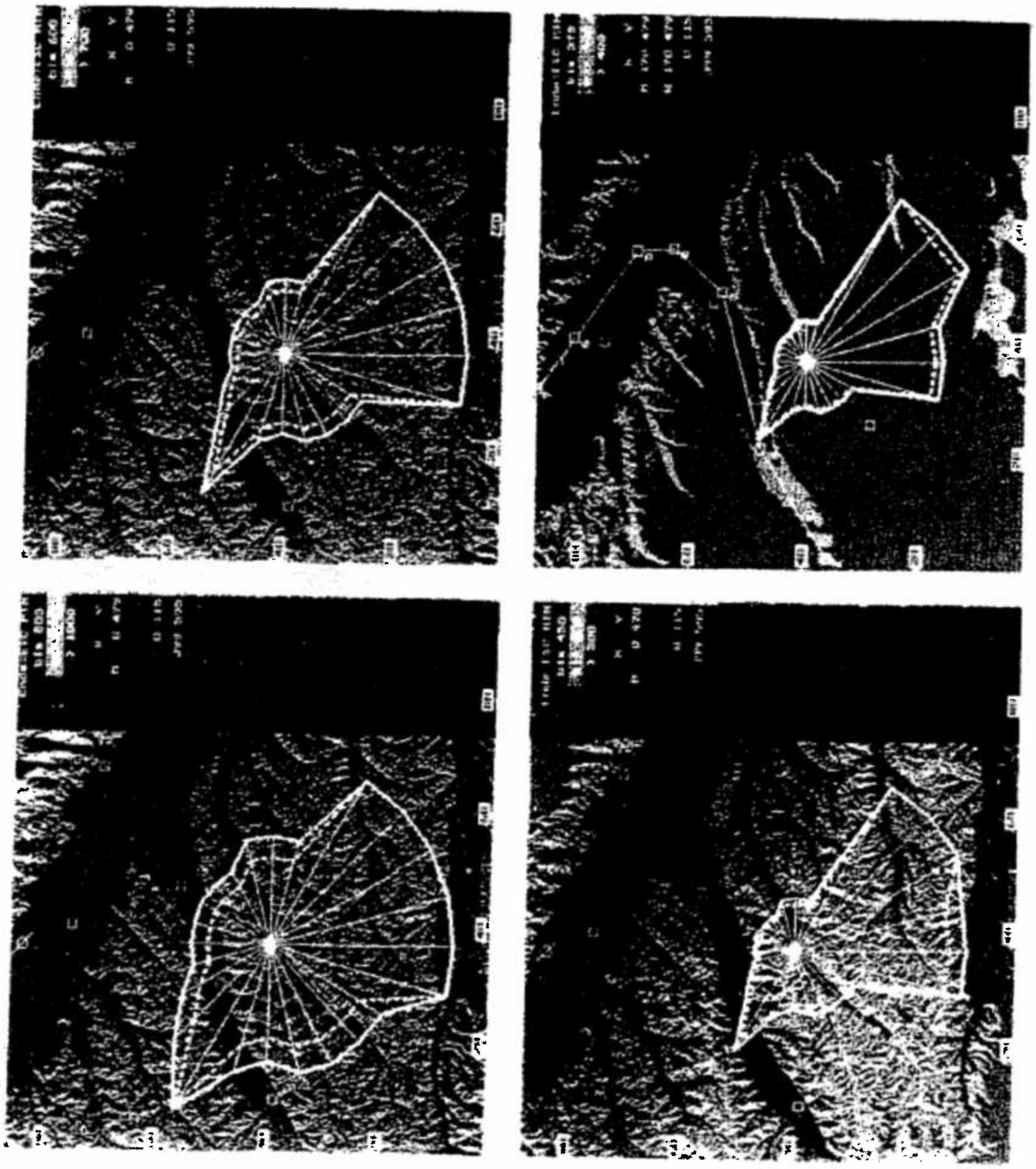


Illustration 7: Display of acquisition / threat areas related to various operating altitudes

2.4 Terrain cross-section display

Illustration 5 shows the course of the terrain elevation between flight path point 1 and flight path point 7 at the lower edge of the display. The six flight path segments are separated by vertical lines.

The horizontal red line represents the assumed or actual operating altitude of 450 m, and the green line represents the elevation of 400 m. This elevation range represents the previously mentioned safety distance below the aircraft. As one can see, the terrain elevation of 400 m is reached only along the first flight path segment between flight path point 1 and flight path point 2; therefore, a safety distance of 50 m between the aircraft and the ground is given even along this critical flight path segment. In the other flight path segments, the distance is always more than 50 m. If correspondingly lower altitude values are entered for these flight path segments and considered during the flight, then a terrain following function has been realized.

In principle, it is possible to display the cross-sectional view in a larger scale with several sections that are parallel to the flight path, and to analyze it in more detail. This allows a possible deviation from the flight path – e.g. due to navigation errors – to be considered, and safety can be improved.

In principle, it is also possible to run these function during the flight "online" - with corresponding safety precautions and redundancies - in addition to the “offline” analyses of the elevation profile for terrain following; this would permit automatic terrain following to be realized.

2.5 Simple perspective terrain display

Illustration 6 shows a section of approximately 10 km x 10 km around flight path point 2 (white box) in an enlarged perspective display ("cavalier perspective"). The line of sight in this terrain section runs from S to N. In principle, other lines of sight (e.g. in the direction of flight) and other sections can also be displayed.

With this function, a simple 3-dimensional view of a previously unfamiliar area can be displayed to the user – e.g. the pilot. This allows critical flight path segments, approach areas, target areas, or airdrop areas to be visualized and mentally processed before they are reached.

Additional 3-dimensional displays follow later in section 3.

2.6 Acquisition analysis and display

The illustration sequence (Illustration 7 with 4 individual illustrations) shows the behavior of a radar station and its 360 ° all-around radiation, e.g. for air traffic control, as a function of the surrounding terrain topography and various operating altitudes between 1000 m and 400 m above sea level. The effective acquisition range for the own aircraft is 33 km (radius around the own position). Quasi-optical propagation laws are assumed.

The radii displayed here have an angular separation of 15°; it is also possible to use smaller degree increments, e.g. 1 °, in order to carry out more precise analyses of the radar acquisition possibilities.

The solid outer boundary shows the acquisition range based on the terrain topography for the aircraft with an operating altitude of 1000 m; the dashed line applies to the altitude of 800 m (1st illustration). The following illustrations apply to lower operating altitudes; the altitudes used are as follows:

	Illustration 1	Illustration 2	Illustration 3	Illustration 4
Operating altitude	1000	700	500	400
2nd altitude	800	600	450	375

The various altitudes result in the radar acquisition height range of 375 to 1000 m.

Of course it is also possible to analyze and display several surveillance radar systems at the same time (radar chains).

In the illustration sequence, the color of the map display also changes with the reduction of the operating altitude. In the illustration with the operating altitude of 400 m, large areas are red (higher than the operating altitude). The first segment of the flight path is also partly in the red area, e.g. the flight path must be moved to a higher altitude, for example 450 m, in this segment. This altitude is barely outside the critical range, as shown by Illustration 5 (cross-sectional view).

The type of analysis shown here can also be used in order to investigate the communication options of the aircraft with one or more ground control stations or to determine the positions where communication is possible / no longer possible.

2.8 Terrain view analysis and display

This function, which is shown in Illustration 8 below (in four individual illustrations), analyzes which terrain points are visible / invisible for the pilot in a user-defined sector around the aircraft or any other position. In principle, the terrain view function – which here represents the pilot's view – can also be realized for sensors.

The view sector selected here is ±45° to the direction of flight; the observation altitude is equal to the operating altitude (aircraft view); the circular arc distance from the center is the assumed / known meteorological visibility range – 12 km, 16 km, and 10 km was used for the three separate cases.

The first illustration shows that only a small part (approximately 25 %) of the terrain in front of and under the aircraft can be viewed from flight path point 3. At flight path point 3, the terrain elevation is 460 m and the operating altitude 40 m above ground.

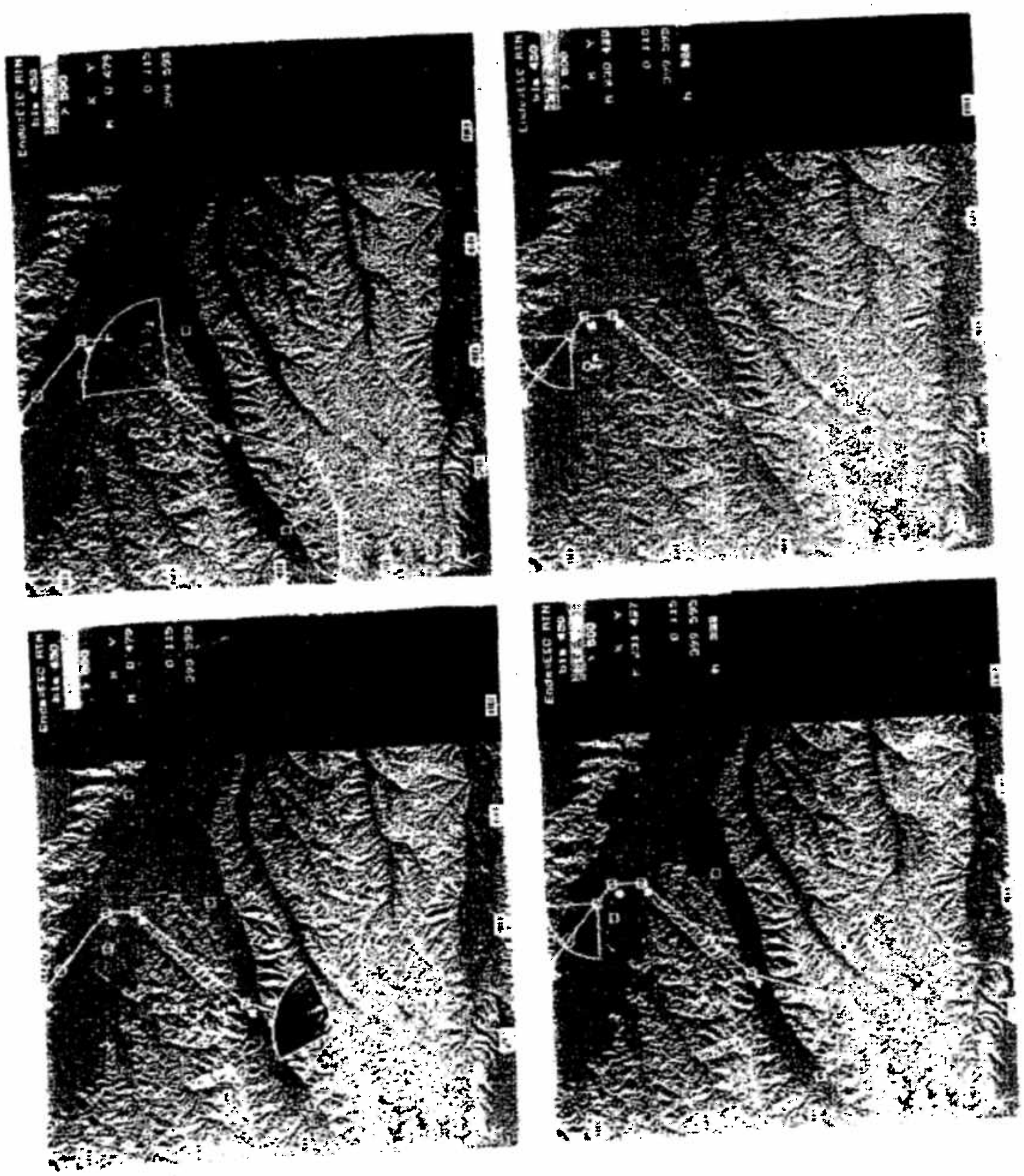


Illustration 8: Display of the terrain view from various aircraft positions (grey areas cannot be viewed)

On the other hand, a much larger part of the terrain (approximately 50 %) can be viewed from the selected point between flight path point 4 and flight path point 5 in the second illustration. At this location, the altitude above ground is 63 m.

This third illustration shows that the target and its surroundings can be viewed with virtually no restrictions 10 km away from the target. The terrain elevation under the assumed / actual aircraft position is also shown in this example (h = 322 m); therefore the operating altitude above ground is 178 m.

The third section was calculated using an alternative altitude of 30 m above ground; as one can see, the view of the target is now partially restricted (individual illustration 4).

Of course, all visibility considerations also apply to the inverse case, that is, the view from the ground to the aircraft; this means that the aircraft cannot be seen from the areas on the ground that are identified in black – there is no visual contact. If the terrain view function is deployed in a correspondingly adapted manner and supplemented with a probability function, then a discovery probability analysis can be carried out for a larger area and the flight path can be selected so that the discovery probability for one's own aircraft is minimized.

2.9 IP overlay

The overlay of scanned images onto the map display is an additional function.

Identification points (IP) can be inserted into the map display at various locations along the flight path. These can be activated as needed or when the point is reached; upon activation, a window that displays the corresponding image by accessing the corresponding image file is opened on the monitor. After use, the window can be closed and the map display restored to the monitor.

3 Perspective views and aircraft control aids

The following illustrations (Illustration 9) are intended as visibility aids for aircraft control in ground proximity. They can be projected onto a HUD or HMD and overlaid onto the actual residual visibility to the outside in poor visibility conditions, e.g. in case of haze or darkness. Of course it is also possible to display the image onto an HDD during standby or backup operation. In flight situations where exterior visibility is barely sufficient, the HDD display can be used for occasional verification.

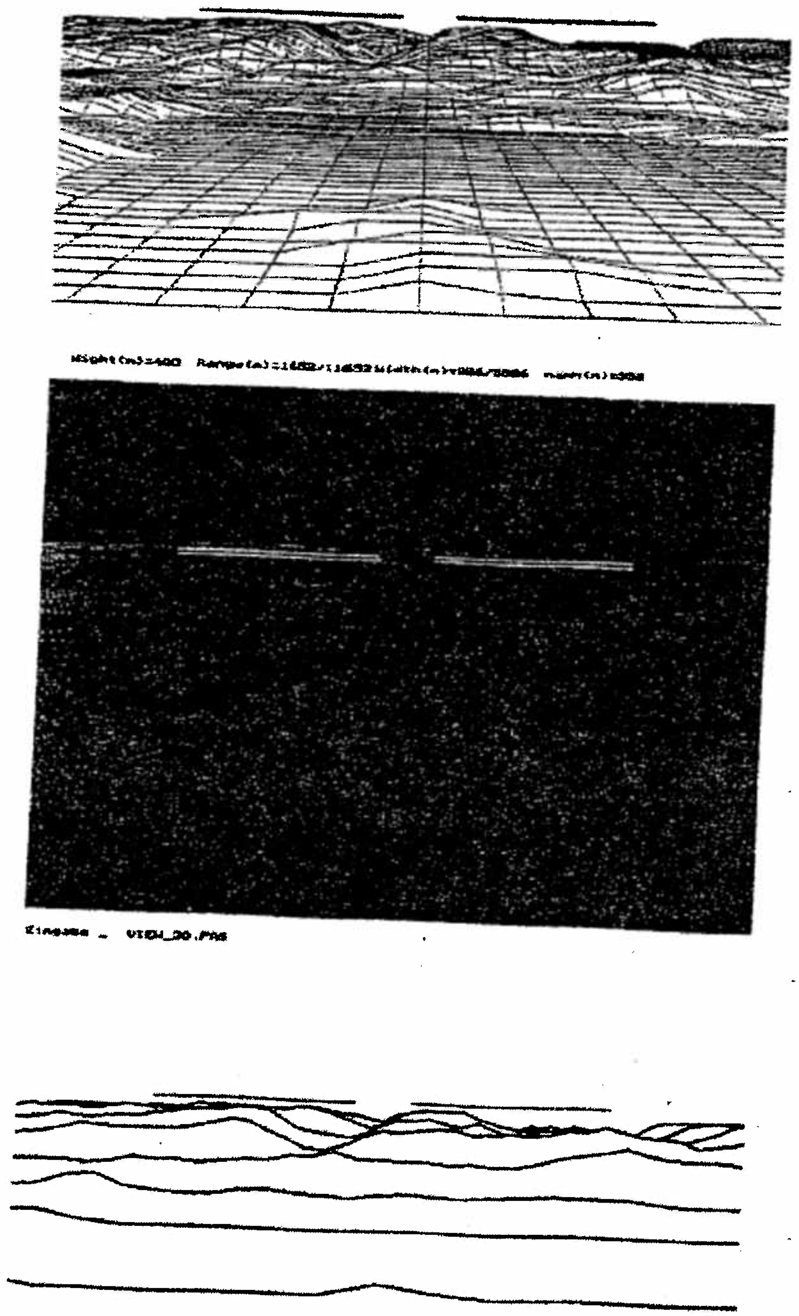


Illustration 9: Simple perspective view as visibility aid for display overlay

Simplified display modes that are also suitable for sensor image overlay, e.g. FLIR, will be shown here as an alternative to photo-realistic processing and display for artificial visibility. These are:

- Grid display
- Point display
- Mountain range display

In order to avoid cluttering the display, none of the illustrations that follow contain aircraft control symbols such as heading and operating altitude scales and an aircraft symbol; the only exception is the artificial horizon as an optical reference line for viewing. Also, "real" terrain that would be recognizable in an operational system with corresponding visibility was not overlaid.

The following information applies to the calculation of the perspective projection of the following illustrations:

- Central projection with a viewing distance of approximately 50 cm from the projection plane = monitor. Monitor size approximately 25 cm x 18.5 cm, aspect ratio 4:3.
- Provision for visibility conditions: Parts of the terrain that are not visible to the observer (pilot) are not displayed (removal of hidden lines / surfaces).
- Field of vision approximately 28° x 21°
- Line of sight angle compared to the horizontal 4°

4 Realization aspects

The illustrations shown here were realized on an IBM PC (386/33 MHz) with a VGA graphics card (640 x 480 pixels, 16 colors). The programming language used was Turbo-Pascal. This development environment has the advantage of fast implementation in terms of "rapid prototyping" which appears especially important for the graphic visualizations. However, "real-time capabilities" cannot be expected due to the limited processing power of a PC.

The "real-time" aspect was investigated in an additional implementation on a graphic workstation from Silicon Graphics Inc. in conjunction with a flight simulator. In summary, in can be said that this computer also fails during concurrent use of several of the functions / display described. However, the software was not optimized for runtime.

Since the trend towards increased data processing power, especially in the graphics field, is certain to continue over the next few years, compact and cost-effective implementations will soon be possible.

Dipl.-Ing. U. Rathmann
ESG mbH
Dept. ET-LT
Vogelweideplatz 9
8000 Munich 81