00598186 E.I. Monthly No: EI7701002230 E.I. Yearly No: EI77029141
Title: REPORT ON THE BOEING FLEET LOCATION AND INFORMATION REPORTING SYSTEM (FLAIR).
Author: Lewis, R. W.; Lezniak, T. W.
Corporate Source: Boeing Co, Wichita, Kans
Source: Kentucky University, Office of Research and Engineering Services, Bulletin n 110 May 1976 Carnahan Conf on Crime Countermeas, Proc, Univ of Ky, Lexington, May 5-7 1976 p 73-85
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Author: Lyons, J. W.; Bannister, J. D.; Brown, J. G.
Corporate Source: Hawker Siddeley Aviat Ltd, Brough, North Humberside, Engl
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Title: OPTIMALLY INTEGRATED PROJECTED MAP NAVIGATION SYSTEM.
Author: Reid, D. B.; Harman, R. K.; Frame, D. J.
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SOME NAVIGATIONAL CONCEPTS FOR REMOTELY PILOTED VEHICLES

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ABSTRACT

This paper discusses methods by which the navigation function for Remotely Piloted Vehicles (RPVs) can be achieved without the need for complex specialised navigation equipment. The objective is to make use of equipment normally carried for RPV operation to supplement a simple dead reckoning navigation system. In this way significant improvements in navigation capability can be achieved with little or no added complexity in the vehicle itself. The additional processing is carried out at the control centre where restrictions on equipment size and cost are not so prohibitive. Both a two-way data link and a forward looking electro-optical sensor are highly desirable RPV facilities and these are on-board equipments that can be adapted to provide additional information at the ground-based or airborne control station for vehicle position updating.

The paper discusses techniques varying from the use of the data link to provide range-bearing navigation to map matching using reconnaissance sensors or a forward looking sensor picture. Use can also be made of an on-board laser to provide range-to-terrain measurements which, when correlated with a computer stored map, enables the RPV position to be continuously updated. Results of simulation studies which have been carried out to validate the techniques and provide an estimate of the accuracies that may be achieved are presented.

NOMENCLATURE

σ_{RPV} = Position error of RPV
σ_R = Range error of DME system
σ_ψ = Bearing error of Data Link
R = Range of RPV from relay aircraft
σ_A = Navigation error of control or relay vehicle
R_n = Range of RPV at the nth sample
ψ_n = Azimuth angle of RPV at the nth sample
Δt = Time between data samples
V_R = Velocity of relay vehicle
θ = Heading of RPV
R_c = Range of RPV from the bisector of the relay station base line
ψ_c = Bearing of RPV from the bisector of the relay station base line
D = Distance between the relay stations forming the base line
R_{IP} = Range from RPV to Identification Point
h = Height of RPV above Identification Point
θ_{IP} = Downlook angle from RPV to Identification Point
θ_L = Laser depression angle
ϕ_i = Laser azimuth angle
RH_i = Horizontal range from RPV to laser/terrain intersection point
ΔH_i = Height difference between terrain at RPV and at laser/terrain intersection point
ε_i = Error in actual/predicted terrain height

1. INTRODUCTION

In recent years the ever increasing cost and complexity of manned aircraft for operation in a battlefield environment has led to a re-appraisal of the use of Remotely Piloted Vehicles (RPVs) for certain types of missions. For high attrition situations in which aircrew are at risk the use of expendable or limited life vehicles is attractive. Provided the vehicle controllers are [illegible] with the necessary guidance and control information, the RPV can possess an operational flexibility comparable with that of a manned aircraft. The roles most suited to a battlefield RPV are :

i) Target Marking
ii) Reconnaissance
iii) ECM

The penetration of the RPV beyond the Forward Edge of the Battle Area (FEBA) necessitates the use of a relay station located such that its altitude is adequate to maintain radio contact with the RPV while its position is such as to be out of range of SAMs. The relay may be either a stationary platform or a patrolling aircraft. In the latter case, the controller can be located in the aircraft. More usual is the use of a ground control station.

The RPV should be as small as possible compatible with the above mission tasks and this means restricting the complexity of the onboard avionics. Although equipment such as forward looking and reconnaissance sensors, a data link and possibly a laser are of necessity located on the vehicle, the navigation and guidance equipment can be largely accommodated on the relay vehicle or at the ground station. The sensors already on board the RPV can be used to provide a navigational facility which can supplement a simple modest accuracy system such as a compass/air data unit. The basic airborne system would provide sufficient information for general flying of the RPV, i.e. heading, velocity and a rough measure of position, while the additional sensors can be used to provide an accurate measure of present RPV position. This philosophy is adopted here and the paper presents a number of alternative techniques whereby, depending on the particular situation, one or more of the above items form part of the overall navigation system.

Firstly, the data link is required to maintain a constant or regular periodic contact with the RPV by means of a narrow beam - width microwave link, hence a tracking facility must already exist on the relay vehicle providing RPV bearing information. Range information can be provided by means of a responsive transponder similar to an IFF system utilising the same vehicle antennas.

Secondly, update facilities can be provided by means of either a real time forward looking or vertical reconnaissance image used in conjunction with a moving map display.

A third possibility makes use of the ranging laser used for target marking purposes. En route to and from the target area, range-to-terrain measurements can be transmitted over the data link to the control station. This data can then be correlated with a computer stored map to determine the most likely RPV position.

The adoption of one or more of the above techniques leads to a significant improvement in navigational accuracy with little or no additional complexity in the vehicle itself.

2. RADIO NAVIGATION USING A DATA LINK

The data link forms the life line of communication between the RPV and the control station. It is the means by which guidance signals to the RPV are transmitted and video signals received. Because of the need for wideband transmissions of video signals (typically 5 M Hz) and the desirability of narrow beam - width, low side-lobe antennas for good anti-jamming capability, microwave frequencies are generally employed. This limits RPV operation to line of sight communication and hence may necessitate the use of airborne relay stations. A possible operational situation is shown in Fig. 1. In practice there may well be more than one relay station and RPV. It is envisaged that the relay station will stand back from the FEBA, out of direct range of ground-to-air weapons. This does not however prevent the enemy making use of either ground or airborne jammers to illuminate the relay vehicle, thereby reducing the effective signal-to-noise ratio of the signals received from the RPV. Two situations can be distinguished, one in which the relative relay - RPV geometry is such that the jamming signals are received by the relay antenna mainlobe, in which case the signal-to-noise ratio is low. The second situation relates more to large lateral separations of jammers and the RPV in which case jamming signals enter the relay antenna via the side-lobes. In such cases, the signal-to-noise ratio may not be significantly degraded and unimpaired operations can continue.

When the effects of enemy ECM can be neglected, i.e. the relay station remaining in contact with the RPV, angular information is directly available from the data link antenna and range can be derived using conventional DME techniques. Thus the position of the RPV relative to the relay station can be reasonably well defined. For absolute location of the RPV, clearly the position of the relay vehicle needs to be defined. In the case of tethered platforms this is no problem but for patrolling aircraft or hovering vehicles the error of the relay vehicle navigation system has also to be taken into account. An overall error can be estimated from the following equation.

$$\sigma_{RPV} = \left(\sigma_R^2 + \sigma_A^2 + R^2\sigma_\psi^2 \right)^{\frac{1}{2}} \qquad -(1)$$

Typical results are presented in Fig. 2.

Perhaps of more importance is the dynamic problem of guiding the RPV to a given position. For this case it is desirable to have a good knowledge of the RPV heading and velocity as well as its present position and best results are obtained by using both on-board and remote guidance equipment. For example, estimates of heading and velocity provided by the compass/air data system can be compared with time dependent range and bearing data derived from the data link to obtain improved estimates of RPV position, velocity and heading. Figure 3 shows the geometry relevant to a 3 point moving window tracking technique. The heading of the RPV can be written in functional form as

$$\theta = f\left(R_{n-1,n,n+1}, \psi_{n-1,n,n+1} / \Delta\tau, V_R \right) \qquad -(2)$$

This generally requires more processing effort than the determination of range or velocity. For tethered or hovering relay vehicles V_R is clearly zero in the above equation. Since the on-board and remote systems use independent data the results are best combined using a statistical filter. The simplest approach is to use a least squares technique (see Reference 1). Alternatively, an integrated filtering method as described in Reference 2 may be employed. This latter paper suggests a significant improvement in navigational accuracies by employing filtering techniques.

In ECM environments, range information to the RPV cannot be guaranteed though it is likely that bearing information can still be derived. To estimate the RPV position in such circumstances, use can be made of the possible multiplicity of relay stations. From known locations of the relay vehicles, cross bearing fixes on the RPV of interest can be achieved. This is a well known location technique, both for air and marine applications. A detailed analysis of the method is given in Reference 3. For the present analysis a more useful expression for position accuracy is

$$\sigma_{RPV} = \sigma_{\psi}\sqrt{2}\,\frac{(Rc^2 - D^2/4)^{\frac{1}{2}}\left((Rc^2 - D^2/4)^2 - (RcD\sin\psi c)^2\right)^{\frac{1}{2}}}{RD\cos\psi c} \qquad -(3)$$

Results derived from equation 3 are plotted in Fig. 4. It can be shown from the above expression that the best accuracy is achieved when $\psi c = 0$ and $Rc/D = 0.3536$. Thus for good accuracy using this technique, the separation between the relay stations should be large compared with the penetration of the RPV beyond the FEBA. To determine the overall RPV position, the additional effect of relay station position accuracy must also be taken into account.

3. MAP MATCHING

So far we have considered on-board dead reckoning and remote radio navigation techniques. The main problem with these techniques is that the position accuracy is either time or range dependent and so additional methods of updating vehicle positions are necessary. A number of techniques are available for an RPV. For reconnaissance vehicles having real time sensors, the problem is relatively straight-forward. The use of either Side Looking Radar (SLR) or Infra Red Line Scan (IRLS) systems means that effectively a map is generated while the sensor is operating. The resulting video signal transmitted to the control station thus provides a method whereby the RPV position can be readily located.

One system widely employed for displaying aircraft navigational information is the projected moving map display and a similar technique can be employed by the RPV control station. Current map systems have the additional facility of being able to combine an electronic display with the moving map and Reference 4 discusses some of the latest developments in this field. Making use of this principle, it may be possible to project the sensor image onto the map and determine the RPV position by matching the two images. Fig. 5 shows the principles of the combined map/sensor display projection system.

In practice it is envisaged that the RPV reconnaissance sensor image will be monitored on a TV display. The use of digital scan converters allows a number of alternative display presentations (see Reference 5). Perhaps the most convenient display mode for the present application is the rolling map or "passing scene" technique where a new line is added to the top of the display and the scene is shifted slowly downwards.

When likely update features are seen (e.g. rivers, crossroads, distinctive man made objects) the frame is frozen, a transfer button is initiated and the digitally stored frame is projected via the map system. The map is then moved laterally to align with the projected image. When the alignment is judged adequate an accept button is pressed and the present position co-ordinates of the RPV updated, taking into account the elapsed time for updating actions. A possible arrangement of operator console is shown in Fig. 6. Control of the image pictures and map matching facility is achieved through the use of a joystick control. Some simulated results of this update technique are shown in Fig. 7. These results make use of SLR imagery.

When the RPV has only real time forward-looking sensors, use can still be made of the transmitted image to provide a navigational update facility. However, in order to create the correct perspective map-like projection, appropriate transformation of the image is necessary. In photogrammetrical language this is termed rectification though the appropriate term in perspective art is anamorphic projection. The principle involved is shown in Fig. 8. The received forward looking image may be co-ordinate transformed either by optical techniques utilising anamorphic lens systems or electronically by means of the scan converter or projection CRT sweep circuitry. Since the image already exists in electrical form, the electronic transformation techniques are probably most suitable. The map type image projected onto the display is now trapezoidal in shape because of the transformation. Major features on the map can again be aligned as described above. In practice several factors combine to make the task more difficult than for the vertical sensor case :-

i) varying resolution, contrast and intensity across the display.
ii) distortion due to undulation of the terrain.
iii) the wildly exaggerated size of trees, hedges, buildings etc.

Hence an alternative simpler update technique is proposed for this situation.

With a forward looking sensor display it is possible to mark objects electronically with a joystick controlled marker symbol; this is standard HUD technology. The electronics can be arranged such that having frozen a suitable image and marked an identifiable point on it, a marker symbol appears on the projected map. Also the field-of-view of the sensor, as projected in the horizontal plane, is superimposed on the map as a "bright up" presentation so that the orientation of the sensor view is clearly seen. The same joystick is now used to align the map with the marker. To ensure correct alignment at least two identification points (IPs) are required on any given image, preferably three or four. In a conventional airborne situation the task of marking a target on a display is not easy and may take several seconds. For the situation described above, however, the problem is one of marking chosen objects on a frozen image in a shirt sleeve environment and hence this aspect of the navigation problem is not considered too difficult.

Fig. 9 shows some simulated results of the above update technique. The effect of the bright area is clearly seen in relati[illegible] marked targets.

4. TERRAIN MAP CORRELATION

Reconnaissance or forward looking sensors provide a convenient method of updating the navigation system. However, these sensors require a large data link bandwidth to transmit the video pictures to the control centre and hence are vulnerable to ECM. Reduction of the video bandwidth reduces the effect of ECM but with a consequent degradation of picture resolution. Hence an alternative method of updating the navigation system is desirable. The method to be described uses ranging measurements made by the laser and compares these with corresponding ranges obtained from a representation of the terrain stored in a computer at the control centre. The data link bandwidth required to transmit the laser ranges is very small and hence is correspondingly less susceptible to interference by ECM.

Basically the technique depends on an adequate representation of the terrain over which it is intended to fly the RPV. The terrain is stored as a series of height ordinates obtained from a map of the relevant area and these are used to construct a computer model of the terrain (Fig. 10). The initial effort in producing this data base from the map is considerable but for a given area it is a 'once-only' task. A simulation of the RPV flight path at the control centre then allows laser range to be calculated for each RPV position and a comparison made with actual ranging measurements. A series of positions and headings around the expected values (and limited in deviation from these expected values by estimated navigation errors) are also tested against the actual measurements and the best position and heading for the RPV found.

For a 2-D simulation, where it is only necessary to determine the alongtrack position of the RPV, it has been found that a minimum of three measurements (2 laser - altimeter) are necessary to give a reliable indication of position, while for a 3-D simulation at least four measurements (3 laser - altimeter) are required. These conclusions are based on error-free simulations. However, when errors are taken into account it has been found necessary to considerably increase the number of measurements to effectively smooth out the errors. Apart from the errors involved in the actual laser measurements the accuracy of terrain representation has a considerable influence on the feasibility of the method. In addition, the technique is ineffective over the sea or over flat, featureless terrain. Nevertheless, by combining this method with those described previously, an effective navigation system is offered without the necessity for specialised navigation equipment.

The method has been demonstrated using a computer simulation of both the laser range measurement and range matching processes, bearing in mind that the latter should not simply be a reversal of the former as this would neglect the "real world" errors caused by imperfect representation of the terrain. The simulation of the matching process is precisely the process that is required to be carried out at the control centre, while the simulation of the laser measurement is an attempt to predict the results of actual measurements made from the vehicle during flight. Hence careful representation of the terrain has been used for measurement simulation with terrain data points spaced 100m apart on a rectangular grid.

The range as seen by the laser is calculated by taking a section through the terrain in the direction in which the laser is pointing. Assuming a knowledge of the RPV height above the terrain h (from a radio altimeter) and the laser beam depression angle θ_L, the horizontal range RH and incremental height ΔH of the laser/terrain intersection point Y, relative to the RPV position X, can be calculated (Fig. 11). The following data is then transmitted from the RPV to the control centre :-

i)	height differences	$\Delta H_1 \ldots\ldots \Delta H_i \ldots\ldots \Delta H_n$
ii)	horizontal ranges	$RH_1 \ldots\ldots RH_i \ldots\ldots RH_n$
iii)	laser azimuth angles	$\varnothing_1 \ldots\ldots \varnothing_i \ldots\ldots \varnothing_n$

From a knowledge of RPV velocity and heading and an estimate of likely navigation errors, the current RPV position can be predicted together with a circle of possible error (Fig. 12). A search can therefore be made within this circle to determine the most likely RPV position. For each position considered, the terrain height H is known from the model and at range RH_i and bearing $\varnothing_i$ from that position the expected terrain height is given by $H + \Delta H_i$. This is compared with the actual terrain height at that point (as stored by the model) to give an error ε_i. By considering each RH_i and $\varnothing_i$ ($i = 1$ to n) an RMS error is obtained for each position, and the position with minimum error gives the most likely RPV position.

5. NAVIGATION ACCURACIES

In this section of the paper an attempt will be made to compare the navigation accuracies attainable from the various techniques previously discussed.

For the basic on-board system comprising a magnetic compass and air data unit, the following accuracies are predicted based on currently available equipment :-

heading	1° standard deviation
velocity	2% standard deviation

This gives a position accuracy of approximately 2% distance gone. However, a major source of error will be due to wind; although a correction can be applied, an uncertainty in wind speed of the order of 5 m/s is not unreasonable. Assuming an RPV velocity 200 m/s this represents 2½% giving a resultant position accuracy of the order of 3½% distance gone.

Range-bearing techniques have been used for many years as exemplified by TACAN/DME navigation. When using ground beacons a major source of error is multipath propagation which gives rise to large errors in estimating the bearing to a station. However the modern systems which use airborne beacons overcome this problem and this is the situation which exists when considering RPVs.

Clearly target bearing estimation from the relay vehicle is a major contributor to RPV location accuracy. Since microwave frequencies, perhaps at X-band, coupled with monopulse determination techniques are employed in the relay vehicle, good angular estimates of the RPV bearing are available. Final figures are dependent on antenna size, frequency of operation and signal-to-noise ratio. It is considered that at least 1° standard deviation should be readily attainable in a practical system. From Fig. 2 it is seen that this gives a typical RPV position error better than 2 km standard deviation at 100 km range. The ultimate short range accuracy is clearly dependent on the accuracy of the relay vehicle navigation system.

When jamming environments are such that perhaps only bearing information is available to the relay vehicles, the cross bearing fix principle utilising multiple relay vehicles remains a possibility for RPV position fixing. Fig. 4 shows the accuracy function on a relative scale and clearly indicates the position dependent accuracy effect. To utilise this technique successfully in a practical situation, it is necessary to carefully select the patrol station positions for the relay vehicles relative to the battlefield.

Taking the 50% accuracy contour as a guide to the area of utility of the technique, this corresponds to a distance from the baseline bi-sector roughly equal to the relay station separation. If we therefore envisage RPV operations out to 100 km from the relay, the relay stations should be located 100 km from each other. At this separation, with a bearing accuracy estimation of 1° standard deviation the RPV can be located to a maximum accuracy of 1.6 km standard deviation. Combining this with a typical relay vehicle position accuracy of 0.5 km raises this figure by less than 0.1 km.

Navigation updating using a real time picture from a vertical reconnaissance sensor provides a very accurate means of position fixing. Fig. 7 shows some simulated results based on SLR imagery. The picture quality of these radars is seen to be more than adequate to identify the main geographical terrain and man made features. In the example shown, the river bank provides a good map matching feature. Fig. 7a shows some degree of misalignment of the map and radar image. In Fig. 7b the two are aligned. Some errors are present due to the scale compression effect at ranges close to the RPV and this is reflected in map projection distortion. Even without further video processing to correct this effect, it is considered that a location accuracy of 0.2 km is attainable.

When using a forward looking sensor for map matching the useful range of the sensor is limited to ~ 3 km, hence the matching will be done over a small area and a larger scale map can be used (cf Figs. 7 and 9). This, together with the fact that considerable detail will be visible in the foreground of the display, makes the matching task easier allowing a match to within say 100 m. Unfortunately various system errors can produce incorrect transformation of the display and result in significant position errors. The sources of error and their effects are the same irrespective of whether a full display transformation technique is being used or only marked identification points.

Across track errors should be small since the only error is that due to marking the display in azimuth. Display marking should be possible to within ± 2% full scale, allowing for both operator and marker system errors. For a 30° FOV sensor this corresponds to an angular error of 10 m rads. Display points of interest are expected to be at ranges between 1 and 2 km and for accurate across track matching a near and a far point should be chosen. This will give sensor heading to within 30 m rads and across track errors < 40 m, i.e. the matching is the biggest source of error.

Along track errors can be much greater. The range to an identification point is given by

$$R_{IP} = \frac{h}{\tan(\theta_{IP})}$$

where h is the height of the RPV above the IP
θ_{IP} is the downlook angle from RPV to the IP

The most significant sources of error in determining R_{IP}, with typical values for standard deviation, are

i) Uncertainty in RPV altitude ~ 3 m in 150 m i.e. 2% h

ii) Undulating terrain. The effect of undulating terrain is exactly the same as variations in RPV altitude. Variations ~ ± 20 m are expected, i.e. 13% h.

iii) Display marking. Errors in marking the display in elevation are again estimated at ± 2% full scale. For a 20° vertical FOV this is 8 m rad.

iv) Uncertainty in sensor attitude. The accuracy with which the sensor attitude is known in elevation is dependent on the equipment fit in the RPV. A value of 2 m rad is assumed. If the attitude is not known to this accuracy an estimate can probably be made from the position of the horizon.

For identification points at a nominal range of 1.5 km the above factors give the following independent errors

i) 30 m ii) 200 m iii) 100 m iv) 25 m.

The combined effects of these errors and the basic matching error is 230 m.

As yet it has not been possible to quantify the navigation accuracy that could be achieved by the laser/terrain correlation system. It is a function of the terrain used and the accuracy of terrain representation. Preliminary results of the simulation described previously are available with the effects of errors in

- laser beam depression angle (2 m rad, 1 σ)
- laser range measurement (6 m, 1 σ)
- radio height measurement (3 m, 1 σ)
- terrain height representation (~ 3 m, 1 σ)

represented. These results suggest that the technique is viable. Nevertheless the search technique used to obtain these results was very much simplified; for each navigation attempt the true vehicle position was presented to the system along with numerous points in the search area. In practice, the true position would not be available and some degradation in results would then be expected.

Further work is required to ascertain the relation between navigation accuracy and errors in terrain representation. However, since it appears that terrain representation is an important part of the concept terrain data taken directly from stereoscopic photographs should yield considerable improvement over data taken from maps. Also careful consideration is required of the optimum search technique which should be used in practice.

6. CONCLUSIONS

A navigation concept has been presented whereby a good navigation accuracy (down to ½ km) can be realised for an RPV with the minimum of on-board equipment. Table 1 summarises the accuracies of the various techniques available. It is proposed that several of these be incorporated into the overall RPV control and guidance system so that the controller can select the one most suitable for a given situation.

When a wide bandwidth data link can be maintained the map matching technique using SLR or IRLS offers the simplest and most accurate solution with the forward looking sensor as a good alternative. It does however, impose a large workload on the controller since, depending on the accuracy of the basic on-board system, the updating needs to be performed every few minutes. A separate navigator is therefore envisaged, keeping track of several RPVs. Electronic devices which are currently being developed to perform area correlation for automatic electro-optical tracking may lead to automation of the matching task in the future.

Where the data link is limited in bandwidth the laser/terrain correlation technique should give good accuracy and the process could be completely automated to provide a continuous indication of RPV position. Disadvantages of the system are the large amount of data storage and computation necessary at the control centre, the development work required to produce an operational system and the unsuitability of the system over featureless terrain.

Alternatively recourse can be made to a system based on measurements made from the relay stations. These are well established techniques offering good accuracy at short ranges and modest accuracy at long ranges. Again a completely automatic system is possible.

In the event of a total failure of the RPV control/guidance link, the on-board system would be adequate to allow the RPV to navigate itself back to a pre-defined recovery area.

7. ACKNOWLEDGEMENTS

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TABLE 1

Comparison of RPV Navigation Techniques

Technique	Accuracy-km (1σ)	Comment	
Compass/Air Data Basic On-Board System	3.5 after 100 km	3½% Distance gone Depends on wind estimates	Continuous Navigation
Range-Bearing from Relay Station	1.8 at 100 km range	1° Bearing accuracy	
Cross Bearing Fix from Relay Stations	1.6 at 100 km range	1° Bearing accuracy 100 km baseline	
Laser Ranger-Terrain Map Correlation	0.5	Depends on the accuracy of the terrain representation	
Map Matching with Recce Sensor	0.2	Accuracy limited by display system	Update Techniques
Map Matching with Forward Looking Sensor	0.23	As above. Additional errors due to display marking etc. Altitude 150 m.	

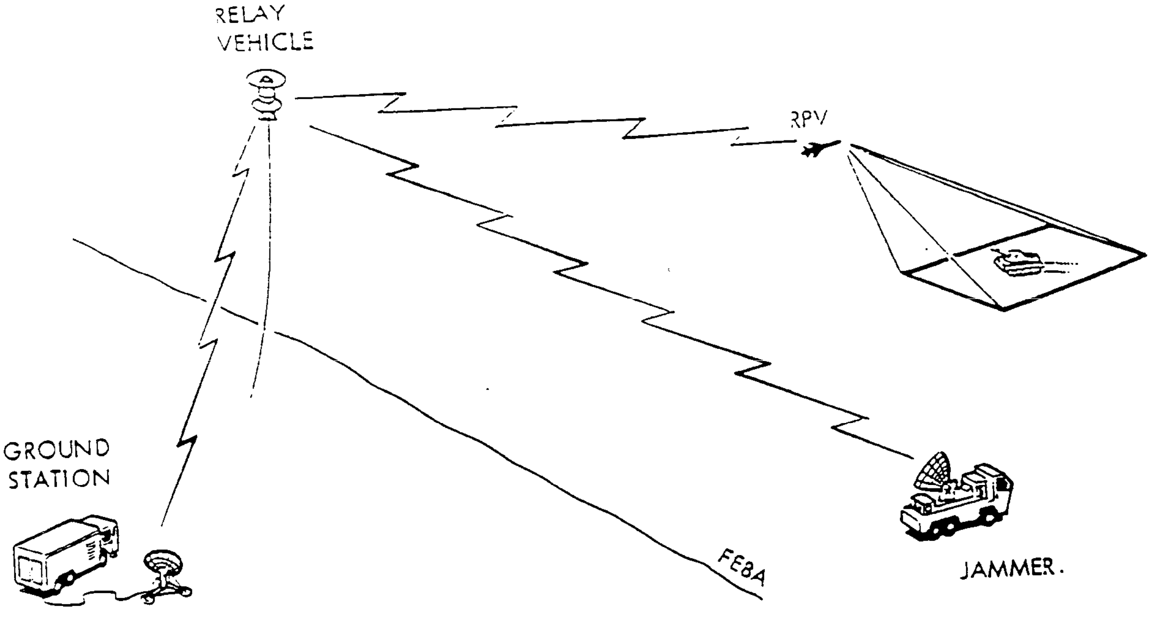


Fig. 1 RPV Operational Situation.

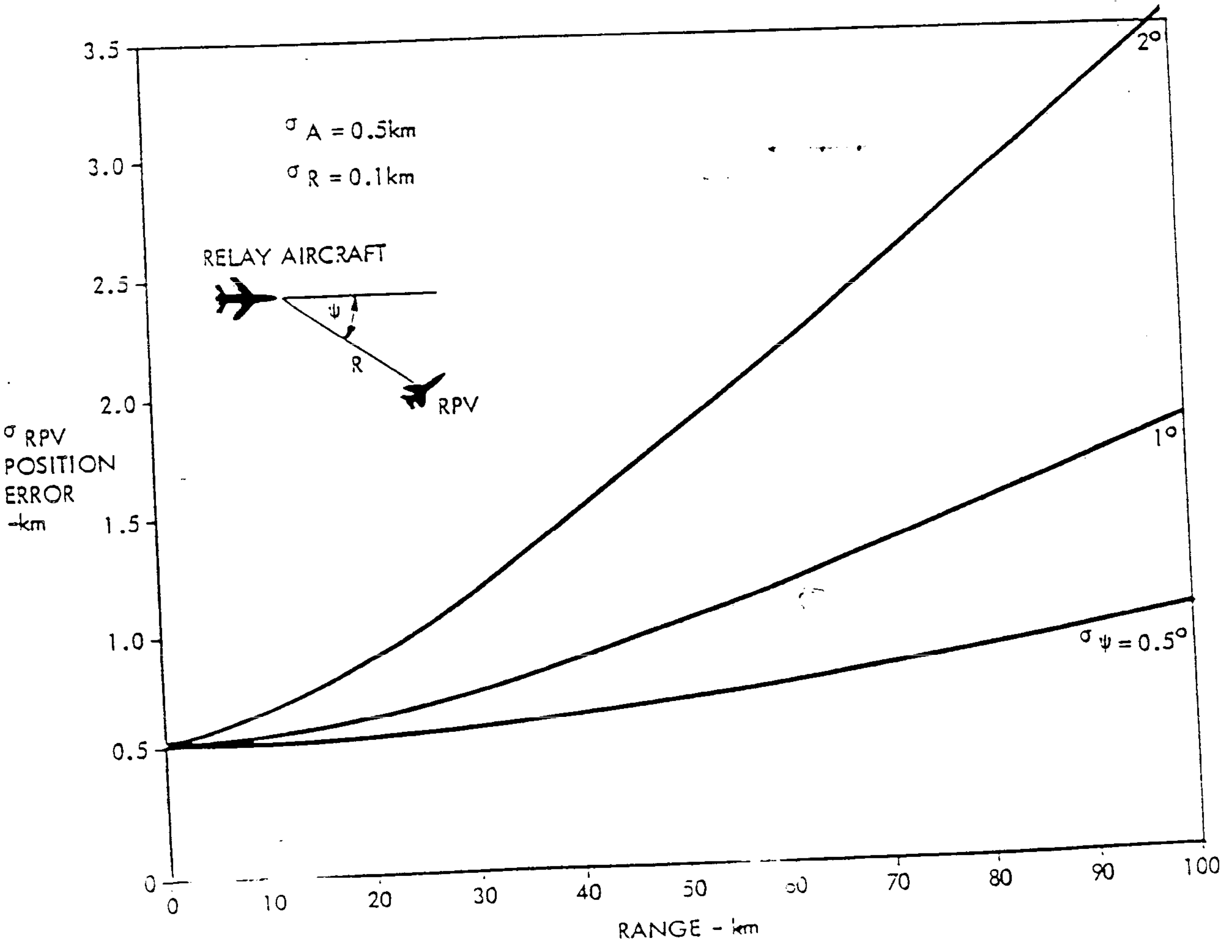


Fig. 2 Accuracy of DME System.

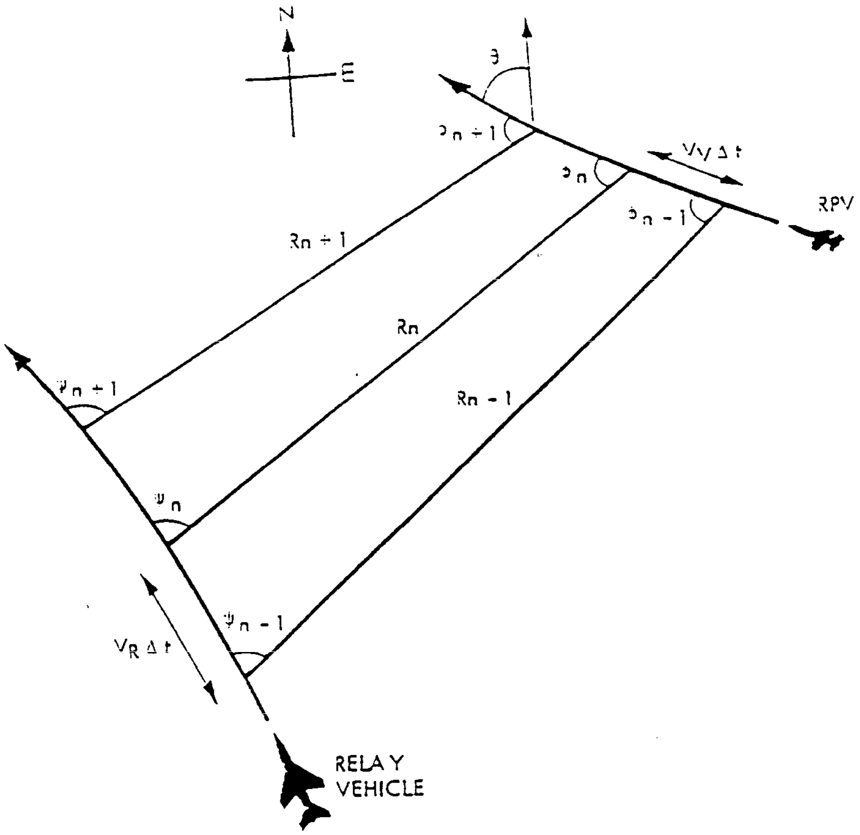
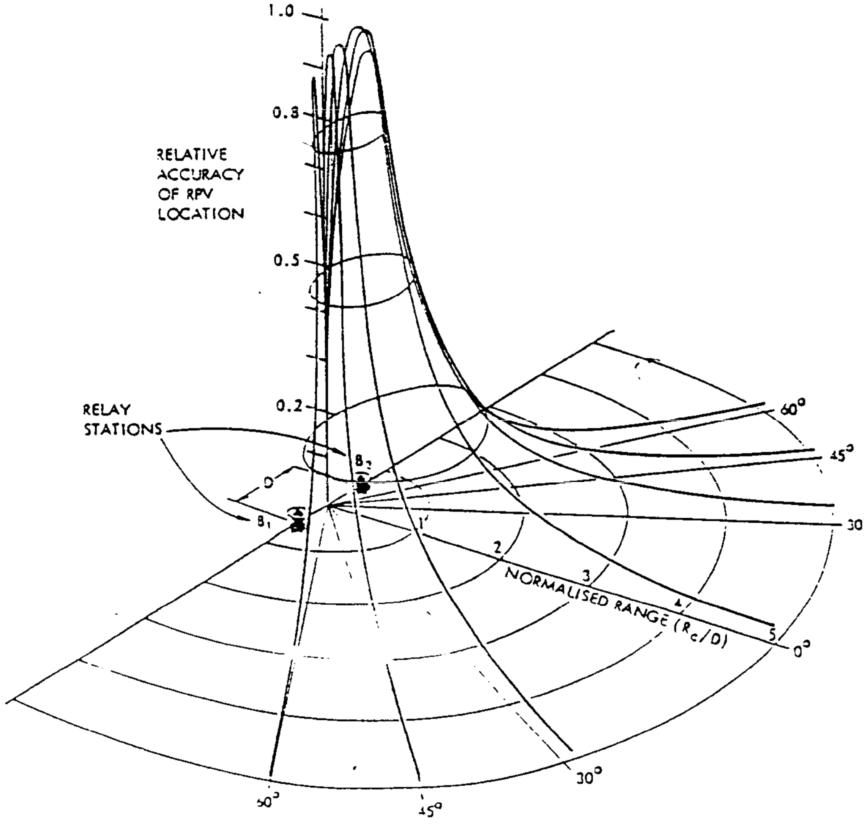


Fig. 5 Moving Window Tracking Technique



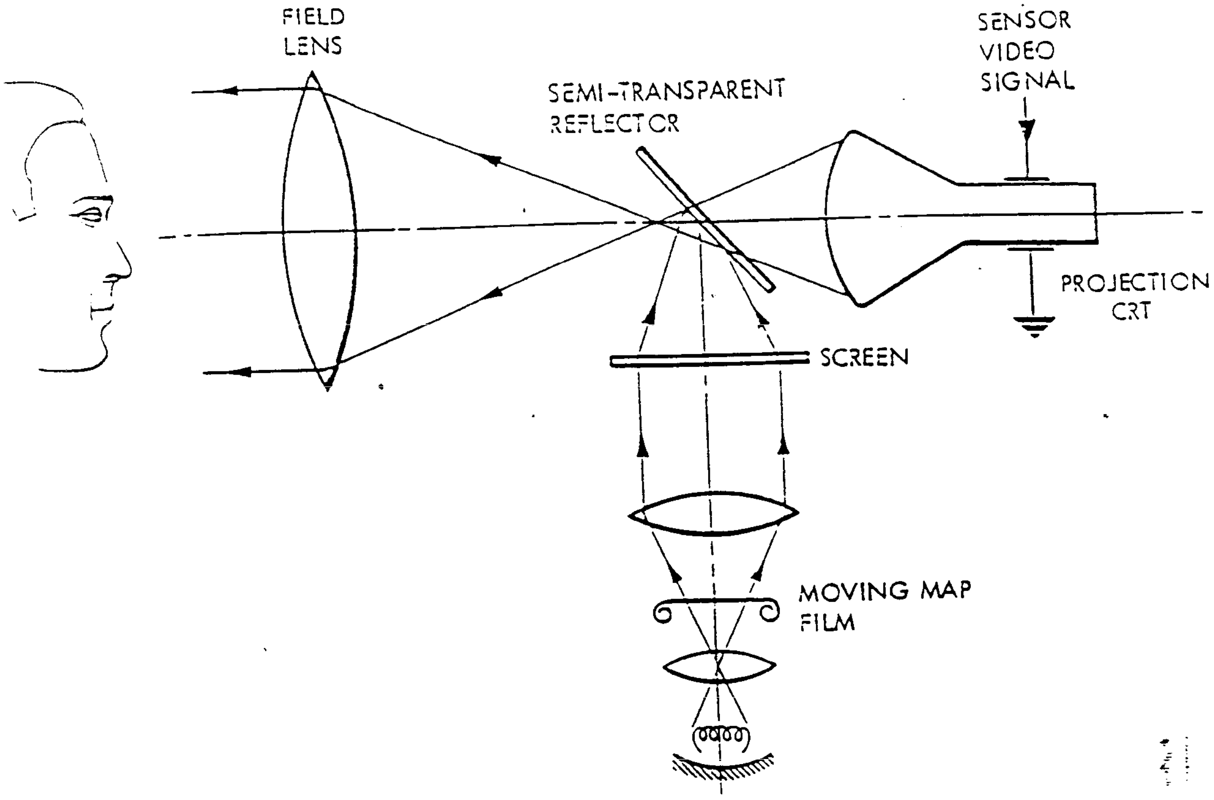


Fig. 5 Combined Moving Map/CRT Display.

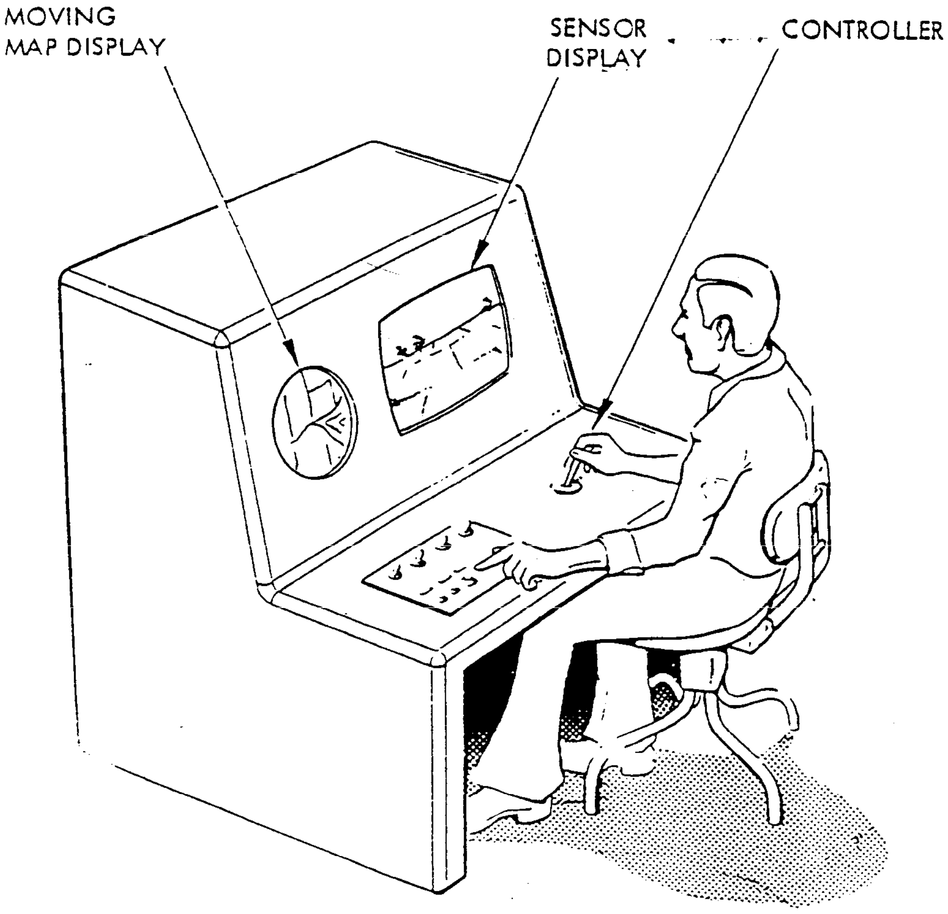


Fig. 6 RPV Controllers Console.

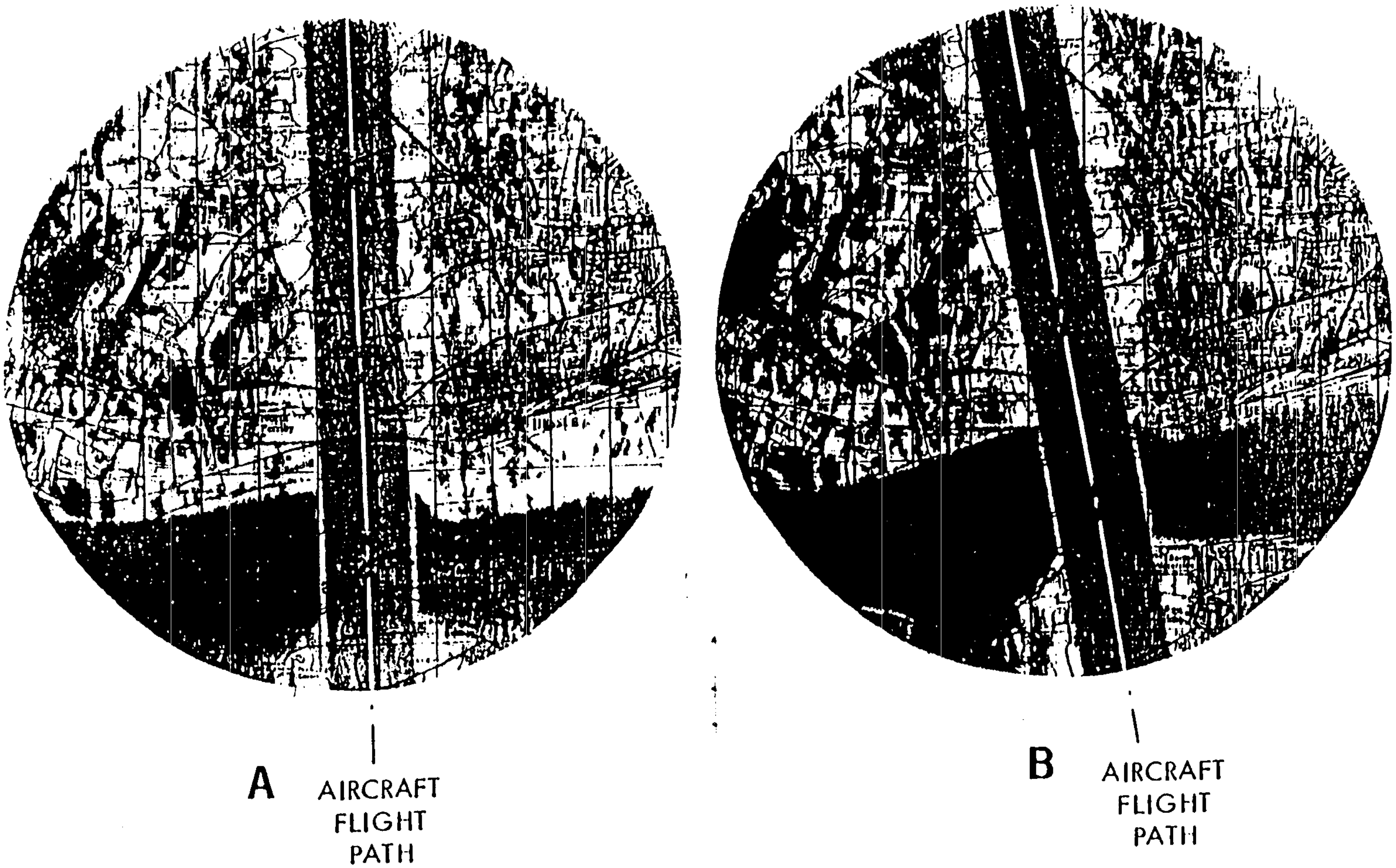


Fig. 7 Simulated SLR/MAP Update System.

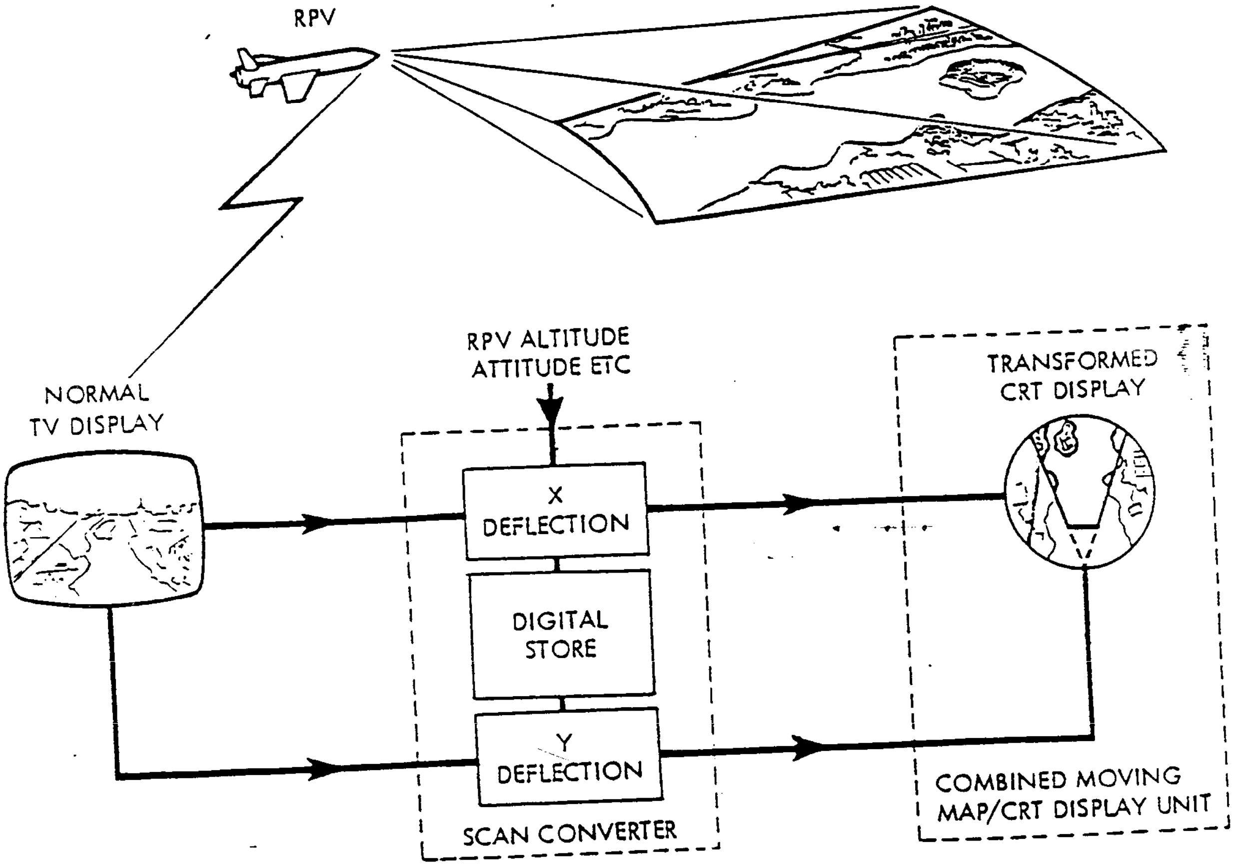


Fig. 8 Forward Looking Sensor Co-ordinate Transformation.

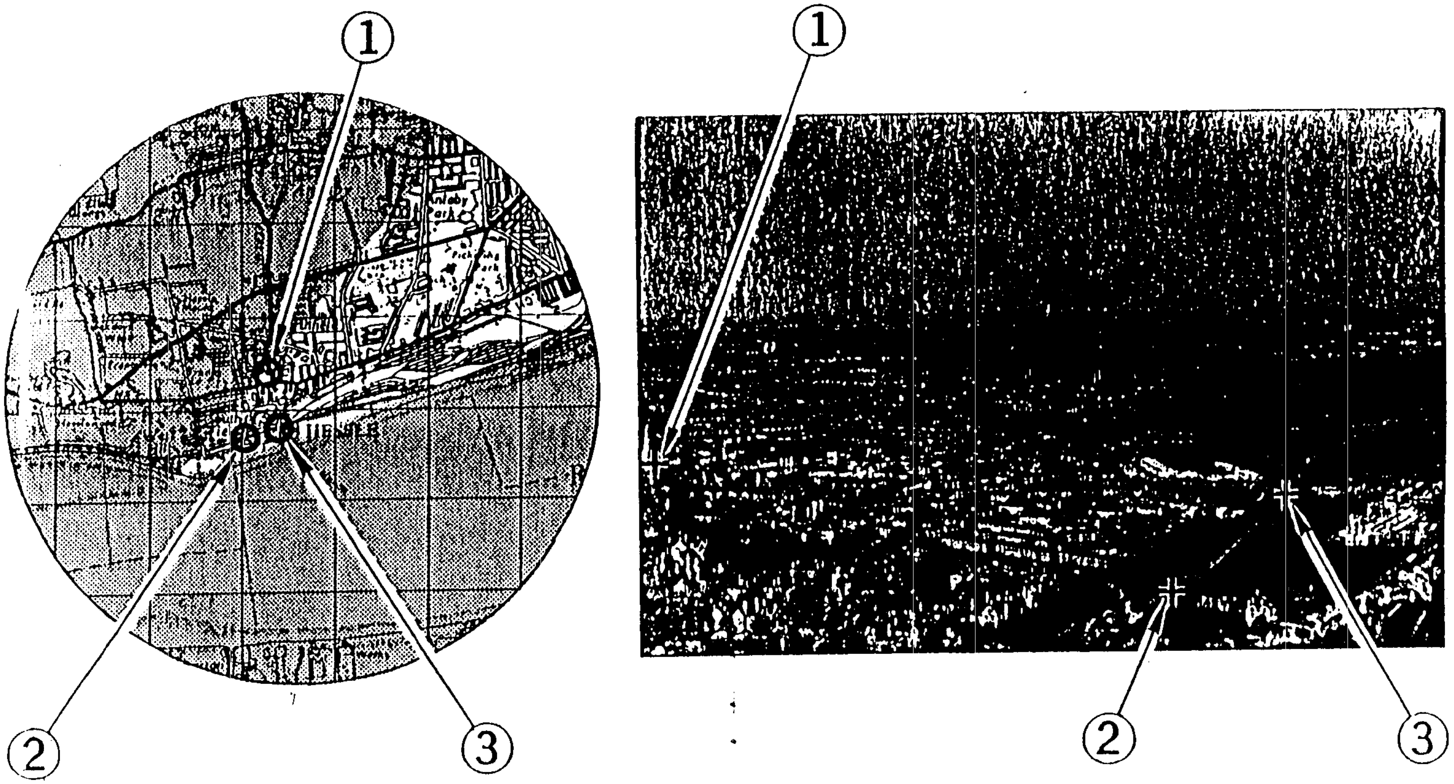


Fig. 9 Simulation of Marked Forward Looking Display/Map Update System.

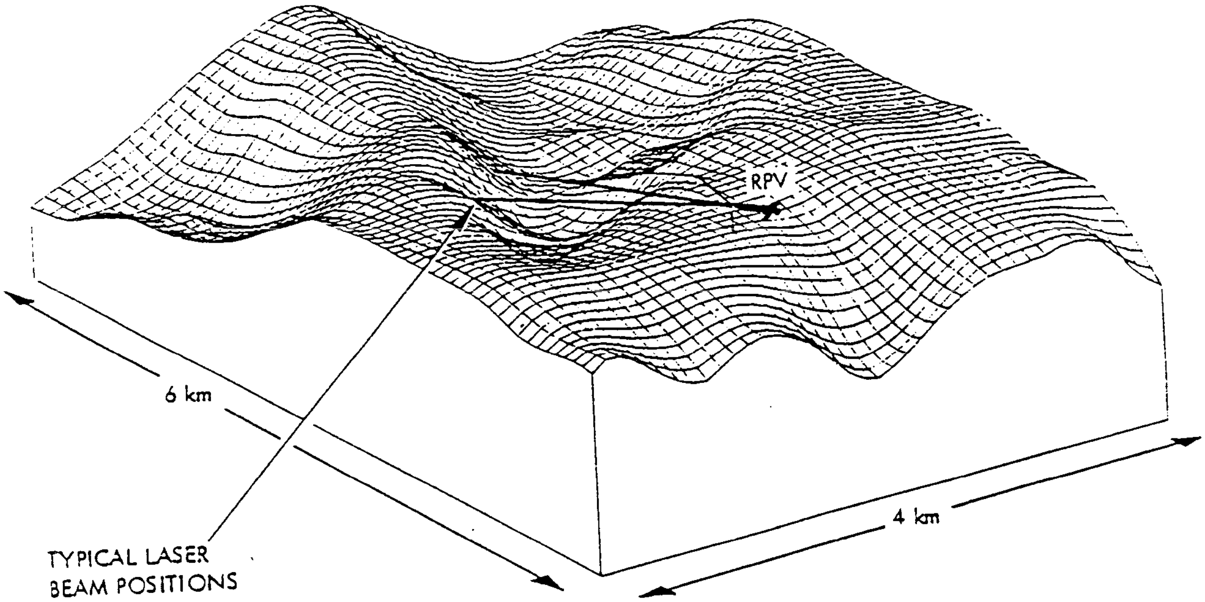


Fig. 10 Terrain Model.

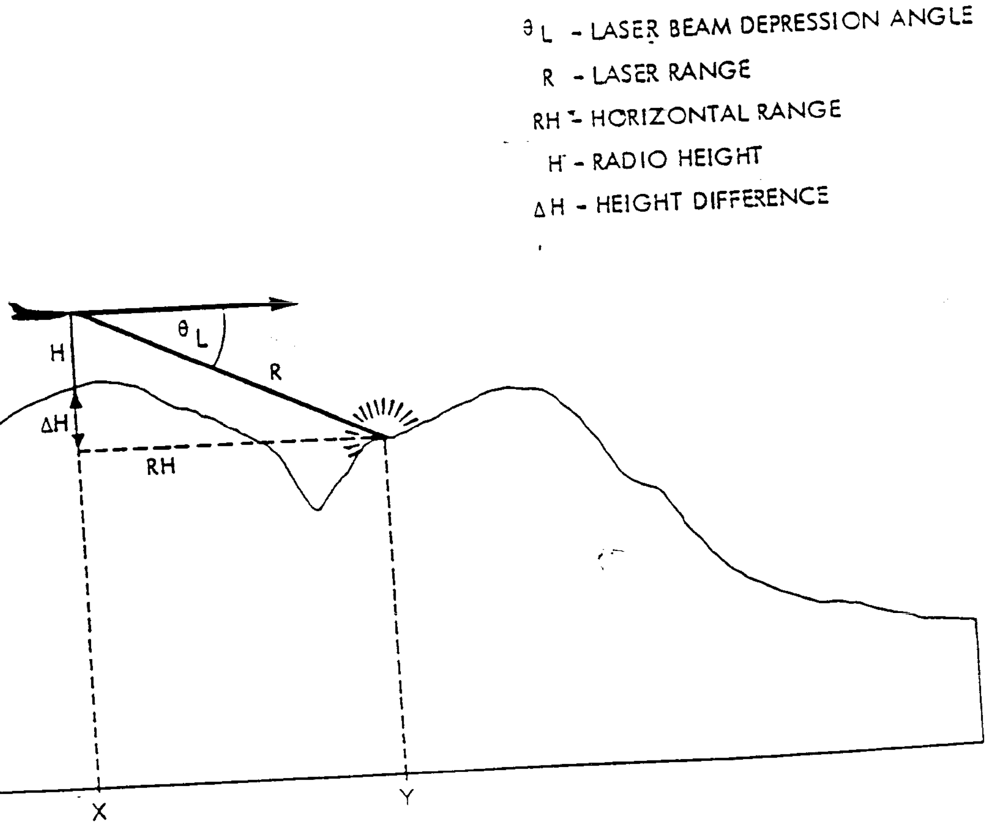


Fig. 11 Terrain Section.

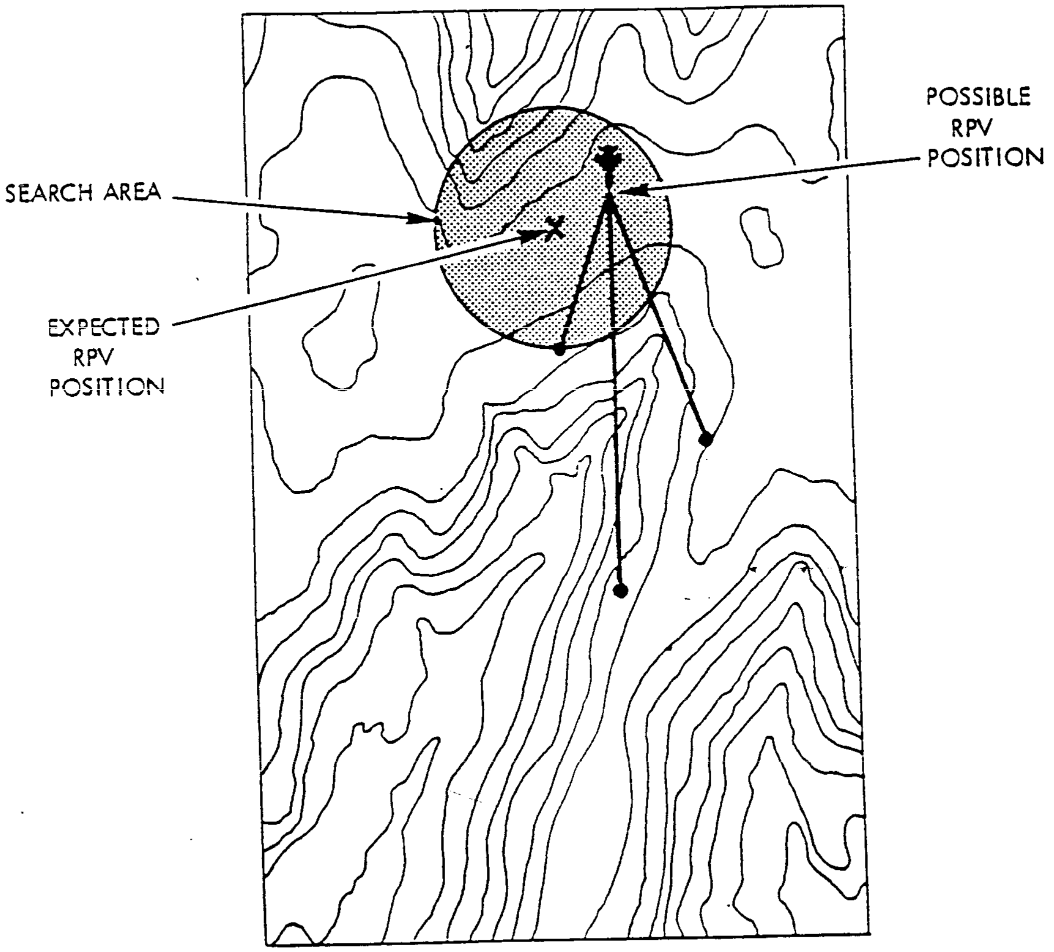


Fig. 12 Terrain Correlation Search.

DISCUSSION

D Halliwell, Decca Systems Study and Management Division, UK

Using the terrain map correlation method, are three ranges really able to give an unique position? There are probably many solutions in each case, only one of which is correct. After a false reset the true position may be outside the area of uncertainty for the next fix. Have your simulations shown any tendency to this effect?

J W Lyons, HSA, UK

For an error-free system three range measurements and radio height will in general be adequate to give an unique position within a limited area, though it is possible to conceive terrain configurations where this would not hold. The method will not work over flat featureless terrain. Also, in a real-world system, errors will be present and further range measurements will be necessary to smooth the effects of these. For convenience and to avoid a cluttered presentation only three measurements were illustrated in Fig. 12.

The area of uncertainty for the next fix depends on errors associated with the estimation of present position. However, when an update is attempted, a confidence level can be estimated based on how well the range measurements fit the stored terrain model. Only when a high confidence level is achieved is an update accepted.

C T J Jessop, Sperry Gyroscope Company, UK

To achieve the fix accuracies quoted what horizontal datum accuracy, in pitch and roll, is assumed for forward and sideways looking laser and radar sensors; and could these in fact approach inertial navigation system accuracy levels?

J D Bannister, HSA, UK

For the small laser beam depression angles assumed, the system is relatively insensitive to small changes in pitch and roll angles. The paper illustrates, in Fig. 11, that it is the horizontal range, HH, which is used for the correlation process. The error in HH will be small. However the question then arises as to the change in terrain height over the distance associated with the error in HH. This will depend very much on the nature of the terrain being overflown. The accuracy of the pitch and roll information thus determines the type of terrain over which the method provides a useful update facility. Also it should be borne in mind that the smoothing effect of taking a number of measurements is very powerful.