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ALGORITHMS AND LOGIC FOR INCORPORATING ILS
LOCALIZER INFORMATION INTO THE NASA TCV B-737
AIRPLANE AREA NAVIGATION SYSTEM

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SUMMARY

This paper presents the algorithms and logic for use in the implementation of instrument landing system (ILS) localizer signals for the generation of navigation information for initial approach guidance. Navigation position estimates are based on position updates determined from range information measured from a DME station (not necessarily colocated with the ILS antennas) and ILS localizer angular information. ILS volumetric coverage and DME geometric checks are performed to ensure that proper radio navigation inputs are being utilized. These algorithms and volumetric and geometric checks are designed so that they could be added to area navigation systems utilizing position difference information to determine navigation estimates with minimum software modification.

INTRODUCTION

Flight tests with the NASA TCV B-737 airplane (ref. 1) have shown that its area navigation system can provide new guidance information presented on cathode ray tube (CRT) displays that results in improved lateral and vertical flight path tracking during an approach to landing. Additional operational experience (ref. 2) has shown that the area navigation system can also provide guidance for flight along curved paths to avoid noise sensitive areas during an approach to landing. To complement the approach to landing guidance, the navigation computer must provide an accurate

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estimate of the airplane's position.

The TCV area navigation system provides an estimate of position from position updates derived from various radio navigation facilities and inertial navigation system derived velocity. It normally uses dual DME radio inputs for enroute navigation and has used microwave landing system signals for precision navigation to provide approach and landing guidance. To ensure that the best possible position estimate is obtained while operating in an area of instrument landing system (ILS) signal coverage, algorithms and logic have been developed that will utilize localizer signals and range information from a single DME station.

The purpose of this report is to describe the equations and logic used to generate a navigation position estimate in the ILS localizer signal environment. The equations used to calculate position difference components derived from 1) ILS localizer deviation measurements and randomly located DME range measurements and, 2) only ILS localizer deviation measurements are described. A summary of the NASA TCV B-737 airplane's estimate process will also be described so that the total navigation process may be shown.

SYMBOLS

A	- distance between the DME and ILS localizer antenna - n.mi.
a	- East component of A - n.mi.
b	- North component of A - n.mi.
D	- DME corrected for slant range - n.mi.
D'	- DME slant range - n.mi.
DME	- distance measuring equipment

$\overline{DP}$ - position difference vector

$\overline{DP}_p$ - component of the position difference vector, $\overline{DP}$, perpendicular to the runway centerline

DP_p - magnitude of vector $\overline{DP}_p$ - n.mi.

dt - cycle interaction time of navigation computer - sec

F - ellipticity constant, 0.003367

$H_{a/c}$ - altitude of aircraft above mean sea level - m

H_{DME} - altitude of DME antenna above mean sea level - m

H_o - altitude of ILS localizer antenna above mean sea level - m

$\hat{i}$, $\hat{j}$ - unit coordinate vectors

ILD - navigation update mode; inertial velocity, ILS localizer, and DME

ILS - instrument landing system

ILX - navigation update mode; inertial velocity and ILS localizer

K_1 - position update gain

K_2 - velocity update gain

L - outer radial limit of localizer volumetric check - n.mi.

M - inner radial limit of localizer volumetric check - m

N,E - axes of orthogonal coordinate system oriented towards True North

P - angle formed by the vector $\bar{Z}_m$ and a line between the airplane and DME antenna - deg

R_E - Earth radius - m

R_M - Meridional radius of curvature - m

R_N - Normal radius of curvature - m

$\hat{u}$ - unit vector perpendicular to the runway centerline

V_N, V_E	-	North and East components of system velocity estimate - kts
$\hat{V}_N$, $\hat{V}_E$	-	North and East components of inertial ground speed - kts
X', Y'	-	axes of orthogonal coordinate system oriented along the runway centerline
X'_e, Y'_e	-	coordinates of vector $\overline{Z}_e$ transformed into the X', Y' coordinate system
$\overline{Z}_e$	-	airplane's estimated position vector
Z_e	-	magnitude of $\overline{Z}_e$ the airplane's estimated position vector - n.mi.
Z_{eN}, Z_{eE}	-	North and East component of $\overline{Z}_e$ the airplane's estimated position vector - n.mi.
$\overline{Z}_M$	-	airplane's measured position vector
Z_M	-	magnitude of $\overline{Z}_M$ - n.mi.
Z_{MN}, Z_{ME}	-	North and East components of $\overline{Z}_M$
$\overline{Z}_R$	-	vector of airplane's position estimated radially along the measured localizer deviation angle
Z_R	-	magnitude of position vector Z_R - n.mi.
Z_{RN}, Z_{RE}	-	North and East components of position vector $\overline{Z}_R$
α	-	angle formed by the DME antenna, origin, and measured airplane position - deg
β	-	angular limit about angle P where DME signal usage will be inhibited - deg
ΔP_N, ΔP_E	-	North and East components of position difference -n.mi.
ΔV_N, ΔV_E	-	North and East components of system velocity update - kts
$\Delta\phi$, $\Delta\lambda$	-	latitude and longitude update estimate - deg
η	-	localizer deviation angle - deg

μ	- relative angle between the DME & ILS localizer antenna - deg
ϕ_{DME}, λ_{DME}	- latitude, longitude of DME antenna location - deg
ϕ_e, λ_e	- latitude and longitude of airplane position estimate - deg
ϕ_o, λ_o	- latitude, longitude of ILS localizer antenna location - deg
ψ_R	- runway heading relative to true north - deg
Ω	- vertical angular limit of ILS localizer volumetric check - deg
ω	- lateral angular limit of ILS localizer volumetric check - deg

Subscripts:

t	- time

DISCUSSION

NAVIGATION POSITION ESTIMATE DESCRIPTION

Position Difference

The TCV B-737 navigation computer is software controlled (ref. 3 and 4) to select and tune two appropriate DME and/or VOR stations in the vicinity of the airplane. A position difference between the point defined by the distance and/or azimuth information received from the stations and the previous position estimate is determined. This position difference is divided into North and East components to be used to calculate a new position estimate.

Other sources of navigation information may also be used to determine position differences. While operating in the ILS localizer environment, these position difference components are calculated with localizer and DME information. This estimation mode is shown on the pilot's electronic map display as ILD (inertial, localizer, DME). If no DME is available, the estimation mode is ILX.

Position Estimate

In the TCV B-737 airplane's navigation system, the same position estimation calculations are used regardless of the manner in which the position difference is determined. The first step in the position estimate process is to develop a system velocity update from the position difference.

$$\Delta V_{N_t} = \Delta V_{N_{t-1}} + K_2\ \Delta P_{N_t}$$

$$\Delta V_{E_t} = \Delta V_{E_{t-1}} + K_2\ \Delta P_{E_t}$$

A system velocity estimate is obtained by summing the system velocity update with ground speed obtained from the inertial navigation system.

$$V_{N_t} = \Delta V_{N_t} + \hat{V}_{N_t}$$

$$V_{E_t} = \Delta V_{E_t} + \hat{V}_{E_t}$$

A position update, in terms of latitude and longitude, is obtained using the system velocity and the position difference as follows:

$$\Delta\phi_t = (V_{N_t}\ \Delta t + K_1\ \Delta P_{N_t})/R_{M_t}$$

$$\Delta\lambda_t = (V_{E_t}\ \Delta t + K_1\ \Delta P_{E_t})/R_{N_t}\ .$$

This position update is based on an oblate spheroid earth model (ref. 3) by using appropriate radii of curvature in the North/South and East/West directions.

$$R_{M_t} = H_{a/c_t} + R_E(1 - 2F + 3F\ \sin^2\ \phi_{e_{t-1}}) \qquad \text{(North/South)}$$

$$R_{N_t} = [H_{a/c_t} + R_E(1 + F\ \sin^2\ \phi_{e_{t-1}})]\ \cos\ \phi_{e_{t-1}} \qquad \text{(East/West)}$$

The updated position estimate is found by summing the previous position estimate with the position update terms.

$$\phi_{e_t} = \phi_{e_{t-1}} + \Delta\phi_t$$

$$\lambda_{e_t} = \lambda_{e_{t-1}} + \Delta\lambda_t$$

ILS/DME (ILD) POSITION ESTIMATE

General Solution

Figure 1 shows the geometry of the ILS antenna, the DME antenna, the airplane's position estimate and its position as measured with ILS localizer and DME information, and the runway with an extended centerline. An orthogonal coordinate system, with its origin placed on the ILS localizer antenna, is oriented in a True North direction. Since the DME may be either automatically or manually selected within geometric constraints relative to the airplane, it is not required to be co-located with the ILS localizer antenna.

By determining the relative geometry between the ILS localizer antenna and the DME and the airplane's position measured with the localizer and DME information, the vector between the origin and the airplane's measured position, $\overline{Z}_{M_t}$, may be found. The vector between the origin and the airplane's previously estimated position, $\overline{Z}_{e_{t-1}}$, may be found directly from their known latitudes and longitudes. The desired position difference used to form a new position estimate may then be found by subtracting $\overline{Z}_{M_t}$ from $\overline{Z}_{e_{t-1}}$.

Calculation of the Airplane Position Vector $\overline{Z}_{M_t}$

Figure 1 shows that $\overline{Z}_{M_t}$ is one side of the triangle formed between the origin (ILS localizer antenna), the airplane's measured position, and the

DME antenna. Known quantities used to determine $\overline{Z}_{M_t}$ in this triangle include the runway heading, ψ_R; the slant range of the DME, D'_t; the ILS localizer deviation angle relative to the runway centerline, η_t; and the latitudes and longitudes of the DME antenna, ϕ_{DME}, λ_{DME}; and the ILS localizer antenna location ϕ_o, λ_o.

Figure 2 shows the angular geometry and distance between the origin and DME antenna, A. The length A and the relative angle between the DME antenna from the North axis, μ, remains constant and is calculated only once. If a new DME is tuned, then A and μ are recalculated.

The length of A is determined by vectorially summing its components a and b.

$$a = (\lambda_{DME} - \lambda_o)(60) \cos \frac{\phi_o + \phi_{DME}}{2} \qquad \text{n.mi.}$$

$$b = (\phi_{DME} - \phi_o)(60) \qquad \text{n.mi.}$$

$$A = \sqrt{a^2 + b^2} \qquad \text{n.mi.}$$

The angle μ is found by

$$\mu = \tan^{-1} \left[{}^{a}/_{b} \right] \qquad o \leq \mu \leq 2\pi$$

The angle α_t, formed by side A and vector $\overline{Z}_{M_t}$, may change with airplane movement and should be continuously recalculated. Angle α_t has a range between o and π, inclusive, and is found by

$$\alpha_t = \left| 2\pi - \mu + (\psi_R - \eta_t) \right| .$$

If the absolute value of α_t is greater than π, then:

$$\alpha_t = \left| 2\pi - \alpha_t \right|$$

The magnitude of the DME reading as measured in the airplane, D'_t is the slant range distance between the ground-based DME antenna and the airplane. This distance was slant-range-corrected to determine the ground distance, D_t, between the airplane and DME

$$D_t = D'_t \sin\left[\cos^{-1} \frac{H_{a/c_t} - H_{DME}}{D'_t}\right].$$

Angle P_t is formed by the vector $\overline{Z}_{M_t}$ and side D_t. This angle may continuously vary and is calculated 20 times per second. Knowing the relation

$$\frac{A_t}{\sin P_t} = \frac{D_t}{\sin\alpha_t},$$

angle P_t is determined by

$$P_t = \sin^{-1}\left[\frac{A_t}{D_t}\sin\alpha_t\right].$$

It must be determined if angle P_t is an obtuse or an acute angle. This is accomplished by comparing the square of side A with the sum of the square of side D_t and the square of the magnitude of the estimated airplane position vector, $\overline{Z}_{e_{t-1}}$. Hence,

$$P_t = \begin{cases} \sin^{-1} \dfrac{A_t}{D_t} \sin \alpha_t & \text{if} \quad A^2_t \leq D^2_t + Z_{e_{t-1}}^2 \\ \pi - \sin^{-1} \dfrac{A_t}{D_t} \sin \alpha_t & \text{if} \quad A^2_t > D^2_t + Z_{e_{t-1}}^2 \end{cases}$$

The magnitude of $\overline{Z}_{e_{t-1}}$ is used as an approximation for $\overline{Z}_{M_t}$. The magnitude of $\overline{Z}_{e_{t-1}}$ is:

$$Z_{e_{t-1}} = \sqrt{Z_{eN_{t-1}}^2 + Z_{eE_{t-1}}^2}$$

in which

$$Z_{eN_{t-1}} = (\phi_{e_{t-1}} - \phi_o)(60)$$

$$Z_{eE_{t-1}} = (\lambda_{e_{t-1}} - \lambda_o)(60) \cos \frac{\phi_o + \phi_{e_{t-1}}}{2}$$

The magnitude of $\overline{Z}_{M_t}$ is found by

$$Z_{M_t} = A_t \cos (\alpha_t) + D_t \cos (P_t).$$

The North and East components of $\overline{Z}_{M_t}$ are found knowing the angle, $(\psi_R - \eta_t)$, between the North axis and $\overline{Z}_{M_t}$.

$$Z_{MN_t} = Z_{M_t} \cos (\psi_R - \eta_t)$$

$$Z_{ME_t} = Z_{M_t} \sin (\psi_R - \eta_t)$$

Calculated of the Position Difference in North and East Components: ΔP_{N_t}, ΔP_{E_t}-ILD Update Mode

The position difference, in North and East components, is now found by subtracting the North component of $\overline{Z}_{e_{t-1}}$ from the East component of $\overline{Z}_{M_t}$ and the East component of $\overline{Z}_{e_{t-1}}$ from the East component of $\overline{Z}_{M_t}$.

$$\Delta P_{N_t} = Z_{eN_{t-1}} - Z_{MN_t}$$

$$\Delta P_{E_t} = ZeE_{t-1} - Z_{ME_t}$$

These position difference components are then used directly in the navigation position estimation algorithms described previously.

ILS LOCALIZER ONLY (ILX) POSITION ESTIMATE

General Solution [1]

In the event that a DME can not be tuned, the navigation computer will utilize the ILS localizer signal and inertial velocity to determine a position

[1] The ILX position estimation mode was developed by the Boeing Commercial Airplane Company at the NASA's request.

estimate. Figure 3 shows the geometry of the ILS localizer antenna, the airplane's position estimate and its estimated position on a measured localizer deviation angle, and the runway with an extended centerline. An orthogonal coordinate system, with its origin placed on the localizer antenna, is oriented in a true north direction.

Radio position difference in the ILX update mode is limited to a direction perpendicular to the runway centerline. Since no DME information is available, a radio position difference cannot be developed in a radial direction from the localizer antenna. However, inertial velocity is still utilized in the radial direction and will supply inputs for a new position estimate in the position estimate algorithms.

North and East position estimates are found in the following manner. A position difference vector, $\overline{DP}_t$, is found by subtracting the estimated position vector, $\overline{Z}_{e_{t-1}}$, from the estimated position vector on the measured localizer deviation angle, $\overline{Z}_{R_t}$. The component of $\overline{DP}_t$ perpendicular to the runway is found and broken into North and East components. These components are used in the navigation position estimate algorithms.

Calculation of $\overline{DP}_t$

To determine $\overline{DP}_t$ it is necessary to calculate the position estimate vector, $\overline{Z}_{e_{t-1}}$, in North and East components from the latitudes and longitudes of the last position estimate and the ILS localizer antenna location.

$$Z_{eN_{t-1}} = (60)\ (\phi_{e_{t-1}} - \phi_o)$$

$$Z_{eE_{t-1}} = (60)\ (\lambda_{e_{t-1}} - \lambda_o) \cos \frac{\phi_{e_{t-1}} + \phi_o}{2}$$

$$\overline{Z}_{e_{t-1}} = Z_{eE_{t-1}}\ \hat{i} + Z_{eN_{t-1}}\ \hat{j}$$

A vector $\overline{Z}_{R_t}$, of the airplane's estimated position along a measured localizer deviation angle is determined in the following manner. Since no radio updates can be obtained in a radial direction from the localizer antenna, it will be assumed that the estimated radial distance from the origin is correct. Hence, the vector length of $\overline{Z}_{R_t}$ and $\overline{Z}_{e_{t-1}}$ will be the same (directions may differ to obtain $\overline{DP}_t$).

The length of $\overline{Z}_{R_t}$ and $\overline{Z}_{e_{t-1}}$ is:

$$Z_{R_t} = Z_{e_{t-1}} = \sqrt{Z_{eN_{t-1}}^2 + Z_{eE_{t-1}}^2}$$

The North and East components of $\overline{Z}_{R_t}$ are found knowing the angle, $(\psi_R - \eta_t)$ between the vector $\overline{Z}_{R_t}$ and the North axis.

$$Z_{RN_t} = Z_{R_t} \cos\ (\psi_R - \eta_t)$$

$$Z_{RE_t} = Z_{R_t} \sin\ (\psi_R - \eta_t)$$

$$\overline{Z}_{R_t} = Z_{RE_t}\ \hat{i} + Z_{RN_t}\ \hat{j}$$

$\overline{DP}_t$ is found vectorially

$$\overline{DP}_t = \overline{Z}_{R_t} - \overline{Z}_{e_{t-1}}$$

Calculation of the Position Difference: ΔP_{N_t}, ΔP_{E_t} - ILX Update Mode

The magnitude of the component of $\overline{DP}_t$ perpendicular to the runway centerline is obtained by the vector dot product of $\overline{DP}_t$ with a unit vector, $\hat{u}$, perpendicular to the runway centerline. This results in the magnitude of the position difference. This magnitude is then multiplied times the unit vector to obtain the position difference in North and East components. These components are then used directly in the navigation position estimate algorithms.

The unit vector, $\hat{u}$, shown in figure 3, is:

$$\hat{u} = -\cos(\psi_R)\,\hat{i} + \sin(\psi_R)\,\hat{j}$$

The magnitude of the component of $\overline{DP}_t$ perpendicular to the runway centerline is:

$$DP_{p_t} = \overline{DP}_t \cdot \hat{u}$$

$$DP_{p_t} = -(Z_{RE_t} - Z_{eE_{t-1}})\cos(\psi_R) + (Z_{RN_t} - Z_{eN_{t-1}})\sin(\psi_R)$$

The North and East components of the position difference are:

$$\Delta P_{N_t} = DP_{p_t}\sin(\psi_R)$$

$$\Delta P_{E_t} = -DP_{p_t}\cos(\psi_R).$$

These position difference components are then used directly in the navigation position estimate algorithms.

ILS LOCALIZER/DME/AIRPLANE POSITION VALIDITY CHECK

Since random DME selection, automatic frequency tunning, and other means of automatic software control will be utilized in the navigation computer, a check must be made to ensure that the navigation computer is using appropriate navigation data that will result in accurate position updating. Obviously, if improper navigation data are being utilized, position estimates based on that data must be inhibited.

To preclude the possibility of using the wrong ILS localizer navigation data, a volumetric geometry check is made to determine if the airplane's position estimate is within the localizer azimuth boundaries. If the airplane is not within these boundaries then ILS updating is inhibited. These boundaries include lateral and radial limits of coverage as shown in Figure 4. The lateral limit of the localizer angle of coverage is $\pm\omega$ from the back azimuth antenna. Radial limits require that the airplane be within L n.mi. of the localizer antenna, but not closer than M meters. A vertical angular limit of Ω degrees from the localizer antenna is also applied to ensure that the airplane's altitude does not exceed the localizer signals vertical coverage. Localizer back course information is not used for updating since all back course signals will not provide valid navigation information.

A new orthogonal coordinate system, with its origin located at the ILS localizer antenna and X' axis parallel to the runway centerline, was used to make the geometric checks. To make the checks, the North and East components of the estimated position vector $\bar{Z}_{e_{t-1}}$, are transformed into the new X', Y' coordinate system as follows:

$$X'_{e_t} = Z_{eN_{t-1}} \cos(\psi_R) + Z_{eE_{t-1}} \sin(\psi_R)$$

$$Y'_{e_t} = Z_{eN_{t-1}} \sin(\psi_R) - Z_{eE_{t-1}} \cos(\psi_R).$$

The lateral azimuth check is then

$$-X'_{e_t} \tan \omega \leq Y'_{e_t} \leq X'_{e_t} \tan \omega.$$

The radial check is

$$M \text{ meters} \leq X'_{e_t} \leq L \text{ n.mi.}$$

The vertical check is

$$H_{a/c_t} \leq H_o + X'_{e_t} \tan \Omega.$$

A geometric check (figure 5) of the DME ground station's location relative to the airplane and runway centerline is continuously performed to prevent the possibility of large position estimate errors caused by the DME inputs. As the angle P_t formed by the localizer antenna, airplane, and DME ground station, approaches 90°, small errors from the DME range information can result in significantly larger radial position errors along the localizer deviation angle on which the airplane is located. Hence, if angle P_t falls within a prescribed angular boundary, β, about P=90°, the DME signal will not be used and a new DME will be tuned or ILX updating will occur. This geometric check is defined as

$$\left(\frac{\Pi}{2} + \beta\right) \leq P_t \leq \left(\frac{\Pi}{2} - \beta\right).$$

CONCLUDING REMARKS

Flight operations of the NASA TCV B-737 airplane have shown the benefits of using the area navigation computer to provide guidance to fly within the ILS area of coverage. Its area navigation system may use various radio inputs to calculate a position estimate for course guidance.

ILS localizer deviation signals may be utilized on the TCV B-737 airplane by algorithms that generate position difference information for use in the area navigation system. These algorithms are designed so that they may be added to area navigation systems utilizing position difference information to determine navigation estimates with minimum software modification.

REFERENCES

1. Morello, Samuel A.; Knox, Charles E.; and Steinmetz, George G.: Flight Test Evaluation of Two Electronic Display Formats for Approach and Landing Under Instrument Conditions. NASA TP 1085, December 1977.

2. Reeder, John P.; and Schmitz, Robert A.: Operational Benefits from the Terminal Configured Vehicle. SAE International Air Transportation Meeting, May 1978.

3. Martin, A. J.; and Cosley, D. H.: ADEDS Functional/Software Requirements. Phase II--SST Technology Follow-On Program. D6-60296, Boeing Commerical Airplane Company, 1973. (Available from DOT as FAA-SS-73-19.)

4. McKinstry, R. Gill: Guidance Algorithms and Non-Critical Control Laws for ADEDS and the AGCS Model NASA 515. D6-41565, The Boeing Company; 1974.

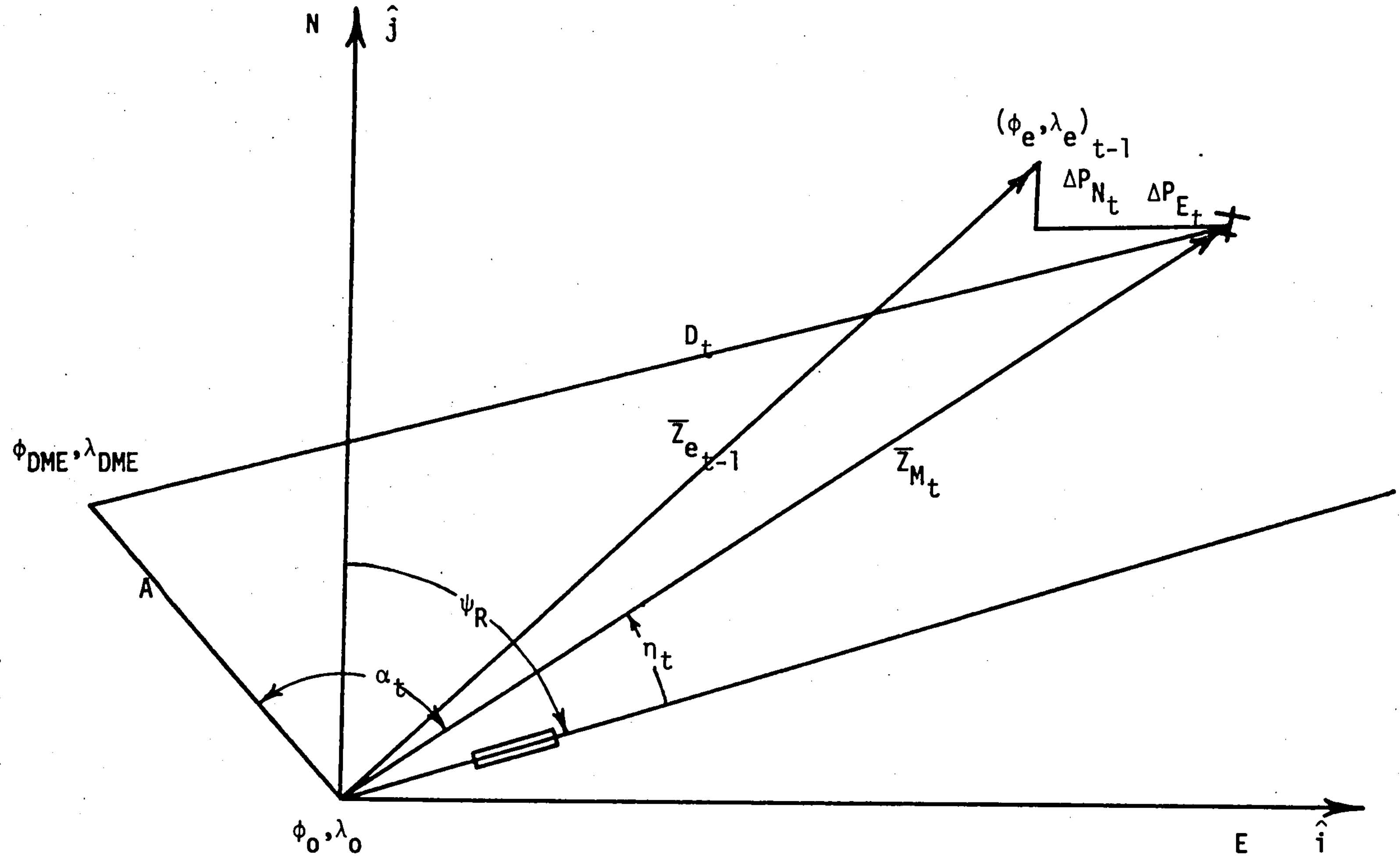

Figure 1.- ILS localizer, DME, airplane estimated and measured positions, and runway with an extended centerline geometry--ILD update mode.

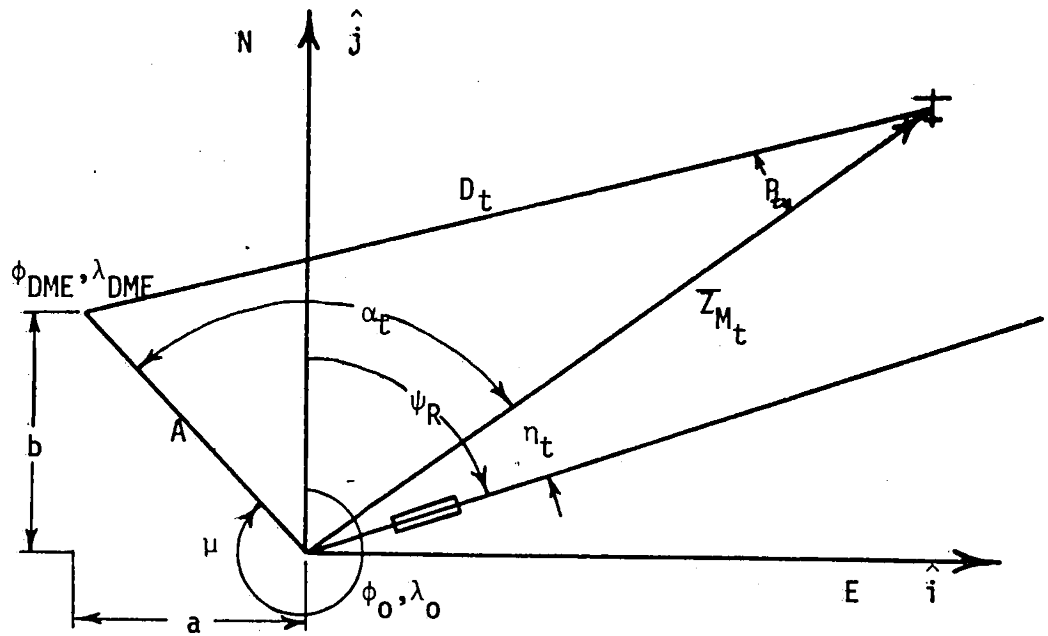

Figure 2.- Vector $\overline{Z}_M$ triangle components--ILD update mode.

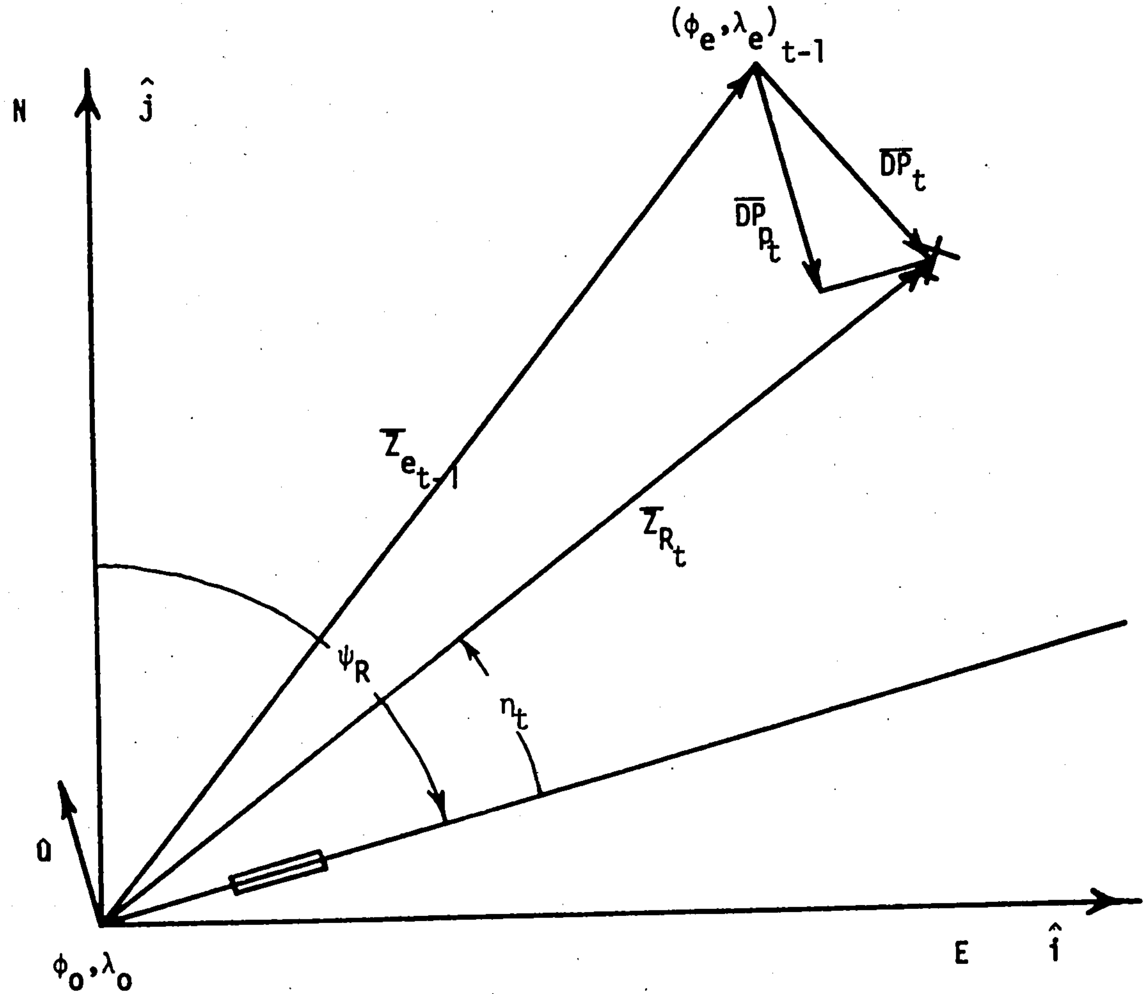

Figure 3.- ILS localizer, airplane estimated and measured deviation angle positions, and runway with extended centerline geometry--ILX update mode.

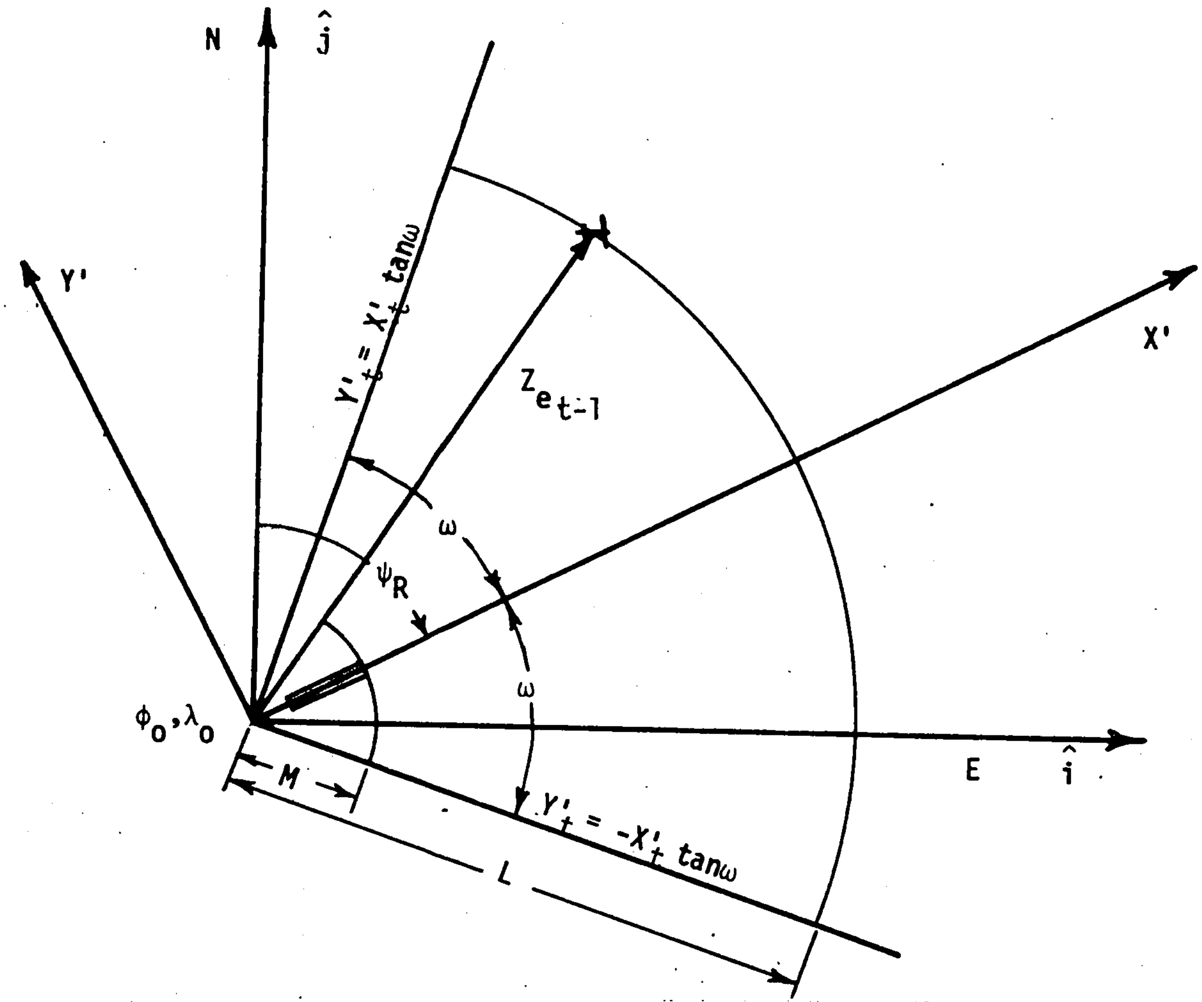

Figure 4.- Lateral and radial ILS localizer geometry limits.

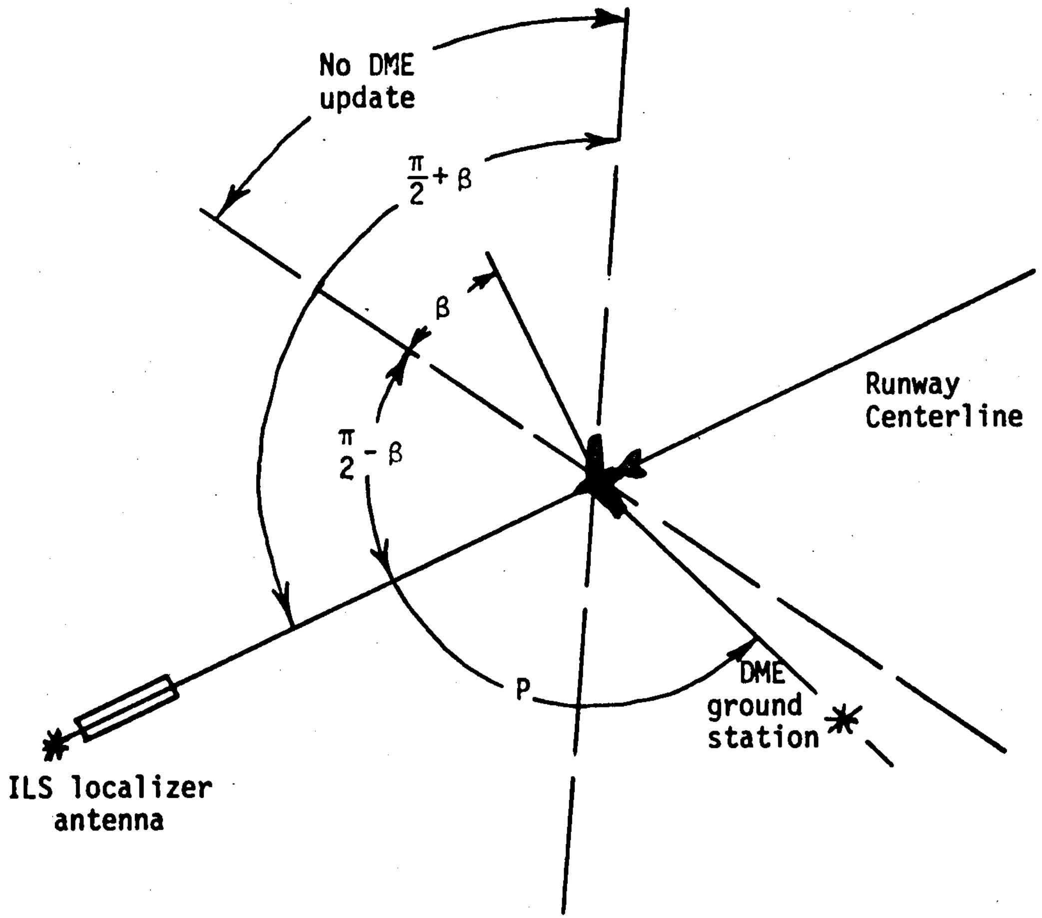

Figure 5.- DME ground station geometry check for ILD position updating.

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16. Abstract

This paper presents the algorithms and logic for use in the implementation of instrument landing system (ILS) localizer deviation signals for the generation of navigation and guidance information. Navigation position estimates are based on range information from a randomly chosen DME and ILS localizer deviation information. ILS volumetric coverage and DME geometric checks are performed to ensure that proper radio navigation inputs are being utilized. These algorithms and volumetric and geometric checks were designed so that they could be added to most existing area navigation systems with minimum software modification.

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