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ALIGNMENT ERROR ANALYSIS OF KAL KE007 INERTIAL NAVIGATION SYSTEM

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ABSTRACT

It is tragic that the Korean Airline Boing 747, KE007, wandered hundreds of miles off course into Soviet airspace and was shot down on September 1, 1983. The exact causes are not known yet. Thus, speculation centers on human error or faulty procedure of three Litton LTN-72R inertial navigation systems(INS) with which the KAL KE007 was equipped.

The inertial platform must be aligned before the INS can be used as a precision inertial navigation system. This analysis checks a possibility that the navigation errors are caused by a wrong INS alignment procedure assuming it is done at Anchorage.

Possible causes for the navigational position error, such as alignment errors and gyro drift errors, are analyzed through inertial navigation system error propagation simulations. A set of misalignment angle is estimated to determine what degree of alignment errors are required to cause the navigation error assuming that the accident is caused by the INS misalignment.

1. INTRODUCTION

Possible causes have been analyzed and published in references (1), (2) and (3).
However any explanations were not satisfactory to all parties involved such as Litton (the makers of the INS), Boing (the 747 aircraft manufacturer), U.S.A., KOREA and U.S.S.R.

An alignment sequence aligns the inertial platform to the present postion coordinates entered by the operator. The alignment sequence takes a minimum of 15 minutes (30 minutes in high latitude regions) to complete for the LTN 72-R.

The alignment of the inertial platform should be done on the ground and the INS should not be moved. The mode switch may then be set to NAV after the alignment has been achieved. Setting the mode switch to other mode during NAV mode destroys the alignment of the inertial platform.

If the three INS were aligned with same wrong position information or the INS were not stationary during their alignment period then the INS will not be aligned properly and will develop position errors during NAV mode and the position errors will not be detected by cross checking each INS position displays.

This paper analyzes the impact of the alignment error on the INS position errors and estimates the initial alignment errors which might lead the KAL wandered to the USSR air space.

2. THE FLIGHT PATH DESCRIPTION

The KE007 was scheduled to take off at 12:20 with flying time of 8 hours 20 minutes to Seoul down the air route known as Romeo 20 which runs across the north Pacific from Anchorage to Seoul. The way points are Bethel, Nabie, Neeva, Nippi, Nokka and Nohho. At Nohho, to the south of Japan, the final waypoints to Seoul would be inserted to the INS. The possibilities of 'finger error' on this occassion have been checked and found to be minimal(Ref.3). A waypoint is a reporting point: over the sea such points are purely geographical coordinates and do not correspond to any natural signpost.

The KE007 took off 13:00 exactly. Fifty minutes out of Anchorage, KE007 radio back routinely to say that it is passing Bethel (346 miles away form Anchorage) but the plane was actually 12 miles to the north of Bethel.

The possible explanations as to why 007 was off course at Bethel are extremely limited. The actual flight path is not known exactly and sketchy to the public except the USSR radar plot for KAL published (ref. 3). The Japan version of radar plot is slightly different from the USSR's. A possible actual route including the shotdown location is simulated and shown in Figure 1.

The KAL flight path which the KAL KE007 might have taken is simulated and shown in Table 1. under following conditions:

Table 1. Navigation Simulation Condition

1. Average speed 435 nm per hour (=550 mph)
2. Leaving time 13:00 gmt Anchorage
3. Reported #1 waypoint time 13:50 gmt 12 miles north Bethel
4. Shot down time 18:28 gmt

A computer indicated simulated flight path is shown in Figure 1. Big arc circle path is assumed between each waypoints. The clash site and the USSR radar plot for KAL positions are also shown in Figure 1.

3. ALIGNMENT ERROR PROPAGATION

It is assumed that the INS system is operated in a mode (damped inertial) such that the so-called uncoupled, small angle psi-equation (4) is applicable. The components of the three-element psi vector represent the relative misalignemnets (errors) between the computer and platform coordinate systems. In vector notation, the psi-equation is given by the differential equation.

$$\dot{\varphi} = -\Omega\varphi + \varepsilon$$

where $\dot{\varphi}$ is the time derivative of φ. The skew matrix Ω represents the rate or the velocity of the inertail system relative to inertial space. The vector ε represents the drift rate of the platform. In general, the matrix Ω is time-dependent, in that it relates vehicle rate in inertial space. The solution of the psi equation is depend upon the initial psi, $\varphi(0)$, and the drift ε. The initial psi represents the misalignment angle.

The latitude error(δL) and longitude error(δl) can be approximated as

$$\delta L \approx \varphi_E$$
$$\delta l \approx -\varphi_N/\cos(\text{lat})$$

Since the drifts in each INS are random and uncorrelated, the position error due to the excessive drift terms can be detected by cross-checking among the argumented triple INS.
If the triple INS are aligned at same time with wrong input then the misalignment will cause position errors. However they may not be noticed by thecking each INS indicated potions.

The psi equation has been simulated with assumed flight conditions given in Table 1.
When the position errors due to the initial misalignment psi, psi(0), are substracted from a INS computer indicated position which the INS computer computes and displays then the resulatant path are simulated possible accidental route. The initial psi-angle (misalignment) is estimated by adjusting the value until the possible accidental route is very close to the assumed clash cite and the USSR radar plot for the KAL. This curve fit implies that the KE007 had flown along the possible simulated route which led to the USSR air space and to be shot down while the INS computer had shown the plane is navigating along the intended Route Romeo 20.

The estimated psi angles are:

$$\varphi_N(0) = -290.1 \text{ arcmin}$$
$$\varphi_E(0) = -\ 10.0 \text{ arcmin}$$
$$\varphi_D(0) = 525.2 \text{ arcmin}$$

The above estimated misalignment angles are very unusally large compare to modern INS specfications. Also it may violate the assumptions of small angle approximation when th psi-equation is derived. However this simulation of linearized psi-equation is one of first steps to analyzing complex non-linear INS equations. The latitude, longitude and heading errors due to the misalignment are shown in Figure 2. It is noted that the heading error is small enough not to be noticed easily by heading reference, magnetic compass.

The longitude error peaks at about 6 hours. If the alignment errors of the three INS are caused by same disturbances such as wrong position information, early wrong mode switch to NAV, and the airplane tow to another location during the alignment period, then resultant position error will not be detected by checking each INS position displays.

4 DISCUSSIONS AND CONCLUSIONS

This paper analyzed possible causes for the KAL 007 accident and theorized that a fault INS alignment procedure possibly caused the airplane wandered to the USSR airspace. This paper estimated INS misalginment angle with which the INS computer indicated position is in route Romeo 20 while the actual flight path is possibly several hundred miles away and in the USSR territory over Sakhalin Island. The misalignment angle is estimated mathematically by a curve fitting to waypoints of the route 20 and to the simulated possible accidental route.

The next logical question about the unusually large misaligment angle is whether it is physically possible assuming an alignment sequence is performed at Anchorage airport. The only imaginable scenario is that the airplane is towed or aligned wth wrong position information during the alignment period. Before pursuing the misalignment hypothesis further we have to examine whether the three INS were passed through an alignment mode at the Anchorage airport. And then we have to examine whether the local-level INS can navigate wihtout any computer overflows due to the large misalignment angle.

It is required that they report to the controller the time of each passing waypoints when they pass. And they did in 50 minutes which should be with a normal flight time from the Anchorage to the Bethel waypoint. It should be answered before a conclusion is made that why it is reported in 50 minutes that they are passing the Bethel waypoint while the INS should have indicated that in 85 minutes after they left Anchorage airport if we assume there was the above analyzed misalignment error. A plausible answer is that they are in heading mode instead of autopilot mode during at that time.

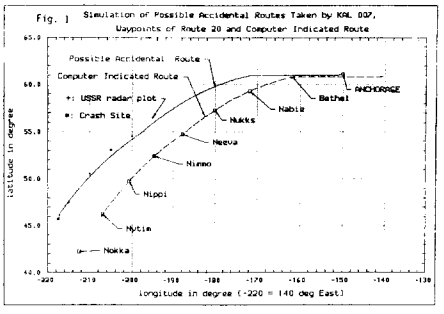

Fig. 1 Simulation of Possible Accidental Routes Taken by KAL 007, Waypoints of Route 20 and Computer Indicated Route

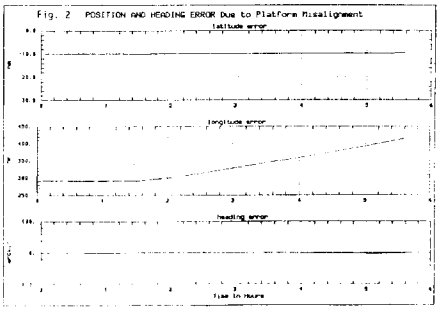

Fig. 2 POSITION AND HEADING ERROR Due to Platform Misalignment

References:

(1) International Civil Aviation Organization (ICAP), Final Report of Investigation as Requiered in the Council Resolution of 16 September 1983 (Reneo, Montreal, Dec. '83)

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(3) Shoot-Down Flight 007 and the American connection by R. W. Johnson, 1986, Viking.

(4) J. C. Pinson, "Inertial Guidance for Cruise Vehicles," in Guidance and Control of Aerospace Vechicles, C. T. Leondes, Ed. NY: McGraw-Hill, 1963