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COMPUTING THE ATTITUDE OF FIXED-WING AIRCRAFT FROM POSITION DAT--ETC(U)
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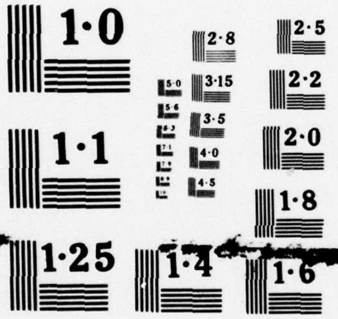
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PAPER P-974

COMPUTING THE ATTITUDE OF FIXED-WING AIRCRAFT FROM POSITION DATA

PROBABILITY OF HIT BY ANTIAIRCRAFT GUNS

J. R. Transue

September 1973

INSTITUTE FOR DEFENSE ANALYSES
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INTRODUCTION

The HITVAL project has identified a need to determine the attitude of fixed- and rotary-wing aircraft participating in a field test.[1] This note presents one method by which the attitude of fixed-wing aircraft can be determined from the time history of aircraft position. The general approach used is discussed below.

During the field test, the position of each aircraft will be accurately determined by tracking systems such as a laser tracker, radars, and cinetheodolites. In the case of fixed-wing aircraft, the time history of position–the flight path–is the result of the forces of thrust, drag, lift, and gravity. An additional force–the side force–also acts on the aircraft if the aircraft is sideslipping. The side force is usually small compared to the other forces.

It is possible to compute the attitude of a fixed-wing aircraft from flight-path data if the weight and a few other characteristics of the aircraft are known and if the side force is negligible. This paper describes a computer program, ANGLE, which performs the necessary calculations. Comparison of the attitude derived from a flight path with the attitude that generated the flight path shows agreement that is usually within 20 mrad. The computer program is based on the F-4 but can be adapted to any fixed-wing aircraft. The same approach cannot be applied in general to rotary-wing aircraft.

The accuracy of the output of program ANGLE depends on the accuracy with which the acceleration of the aircraft can be computed from position data. The noise that is normally a part of data obtained from field tests will degrade the accuracy of the method. This problem may be minimized by using acceleration data from the field tests when these data are available.

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[1] *Design of a Field Test for Probability of Hit by Antiaircraft Guns,* WSEG Report 197, February 1973, p. 31.

THEORY

The method of solution is based on the assumption that the velocity, lift, drag, and thrust vectors are all in a single plane. This is tantamount to saying that there is no sideslip and that the aircraft, including the propulsion system, is symmetrical about a plane. This plane is called the aircraft plane of symmetry.

The net force acting on an aircraft includes the force of gravity–weight–as well as the aerodynamic forces–lift and drag–and the propulsion force–thrust. The force of gravity is essentially a constant vector within the airspace of interest, say within a cube a few kilometers on each side. The net acceleration of a body is the vector sum of the accelerations that would result from each external force acting on the body. Therefore, the acceleration resulting from aerodynamic and propulsion forces can be obtained by subtracting the vector acceleration of gravity from the net acceleration. The program ANGLE does this and then computes the aerodynamic and propulsion forces and the attitude of the aircraft required to develop the aerodynamic forces.

The main steps in the ANGLE computations are as follows:

(1) The velocity and net acceleration of the aircraft are determined from the flight path. This step can be skipped if velocity and acceleration are known, say from field test data.

(2) The vector acceleration of gravity is subtracted, leaving the acceleration due to aerodynamic and propulsion forces.

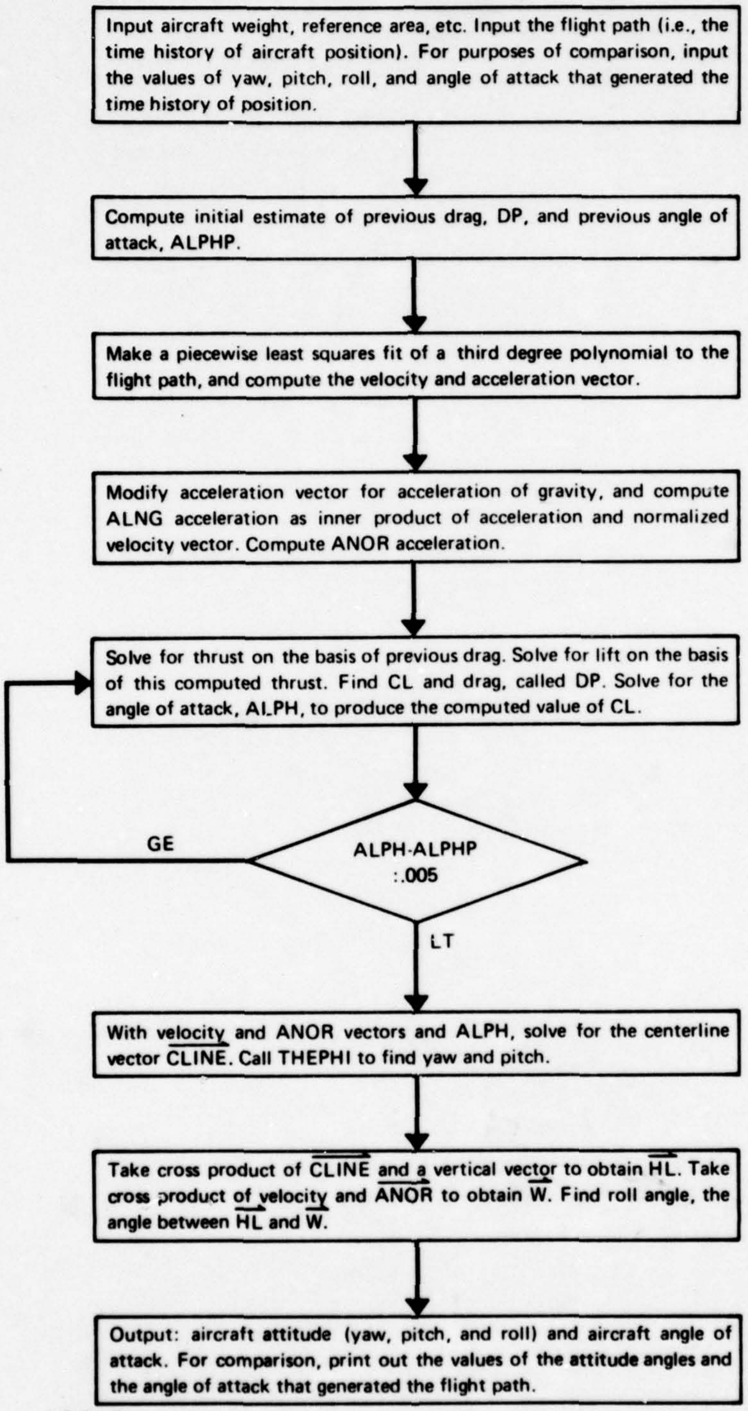
(3) Thrust is computed on the basis of acceleration in the direction of the velocity vector and estimated (previous) values of drag and angle of attack.

(4) Lift is computed on the basis of the computed thrust and the acceleration perpendicular to the velocity vector.

(5) The angle of attack required to produce the lift is computed from known aerodynamic characteristics of the aircraft. This is compared to the estimated value to see if another iteration is needed.

(6) The attitude angles of the aircraft–pitch, yaw, and roll–are computed from the direction of the velocity vector, the direction of the acceleration due to aerodynamic and propulsion forces, and the angle of attack.

These steps are shown in somewhat more detail in Figure 1. The variables are defined in the list on page 20.



Input aircraft weight, reference area, etc. Input the flight path (i.e., the time history of aircraft position). For purposes of comparison, input the values of yaw, pitch, roll, and angle of attack that generated the time history of position.

Compute initial estimate of previous drag, DP, and previous angle of attack, ALPHP.

Make a piecewise least squares fit of a third degree polynomial to the flight path, and compute the velocity and acceleration vector.

Modify acceleration vector for acceleration of gravity, and compute ALNG acceleration as inner product of acceleration and normalized velocity vector. Compute ANOR acceleration.

Solve for thrust on the basis of previous drag. Solve for lift on the basis of this computed thrust. Find CL and drag, called DP. Solve for the angle of attack, ALPH, to produce the computed value of CL.

With velocity and ANOR vectors and ALPH, solve for the centerline vector CLINE. Call THEPHI to find yaw and pitch.

Take cross product of CLINE and a vertical vector to obtain HL. Take cross product of velocity and ANOR to obtain W. Find roll angle, the angle between HL and W.

Output: aircraft attitude (yaw, pitch, and roll) and aircraft angle of attack. For comparison, print out the values of the attitude angles and the angle of attack that generated the flight path.

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Figure 1. Main Steps in Program ANGLE

The computations of thrust and lift are easily derived from Figure 2, which shows the relevant vectors and angles in the plane of symmetry. Summing forces in the direction of velocity gives

$$T \cdot \cos(ALPH + TA) - DP = ALNG \cdot WT/g$$

where g is the acceleration of gravity (9.8 m/sec^2). Summing forces in the direction of lift gives

$$L + T \cdot \sin(ALPH + TA) = ANOR \cdot WT/g$$

The coefficient of lift is defined by CL = L/qS, where q is dynamic pressure and S is a constant reference area known for each aircraft. By definition q (called QUE in ANGLE) is one-half the product of atmospheric density and the square of the aircraft speed. Atmospheric density decreases with increasing altitude. In ANGLE the ratio of density at altitude H to density at sea level is computed from

$$SIG = \exp\left[-.0948\left(\frac{H}{1000}\right)^{1.047}\right],$$

where H is in meters. This compares with the international standard atmosphere as shown in

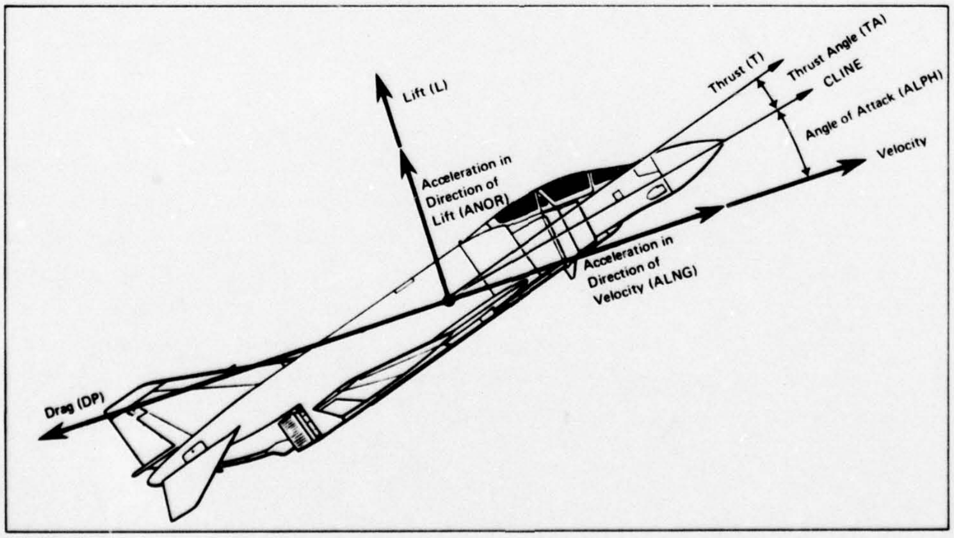

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Figure 2. Vectors in the Plane of Symmetry

Table 1. Then q is computed from

$$QUE = .0624 \cdot SIG \cdot V^2,$$

where V is speed in meters per second.

Table 1. Comparison of SIG with Values from the Standard Atmosphere

Altitude		Computed SIG	Standard SIG
Meters	Feet		
0	0	1.000	1.000
1,524	5,000	0.863	0.862
3,049	10,000	0.737	0.738
6,096	20,000	0.533	0.533

Angle of attack, ALPH, is determined from a piecewise-linear approximation to the known relation between ALPH and CL. The approximation is plotted with appropriate CL versus ALPH curves in Figure 3.

Drag is computed from $DP = C_D qS$, the defining equation for the coefficient of drag. C_D is computed from $C_D = .024 + .3045 \cdot CL^{2.76}$. This function is compared to the function known from empirical data in Figure 4. Note that (1) drag depends on angle of attack and (2) the computation of thrust requires that angle of attack and drag be known. Each computation of thrust uses the previously computed values of angle of attack and drag (hence the nomenclature DP for "drag, previous"). After each computation of angle of attack, the new value is compared with the old value and the computation cycle (beginning with the computation of thrust) is repeated if the agreement is not within 5 mrad. It is seldom necessary to repeat the cycle.

After angle of attack is known, a vector pointing forward along the aircraft longitudinal reference line is computed by adding to the velocity vector a vector that (1) is normal to velocity and in the plane of symmetry and (2) has magnitude equal to speed times the tangent of the angle of attack. The direction of this vector (CLINE for "centerline") determines the pitch and yaw angles of the aircraft.

A horizontal unit vector HL perpendicular to CLINE is found as the normalized cross product of CLINE and a vertical vector. A unit vector W out the right side of the aircraft (perpendicular to the plane of symmetry) is found as the normalized cross product of the velocity vector and ANOR. Then the roll angle is computed as the angle between W and HL.

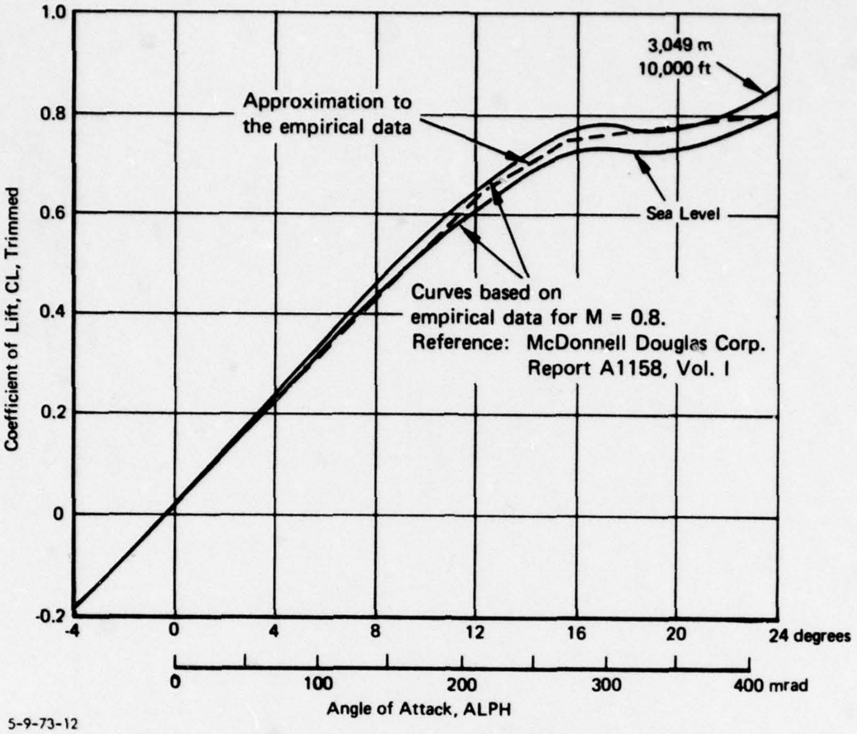

Figure 3. Approximation to CL Versus ALPH Curve, F-4E/J

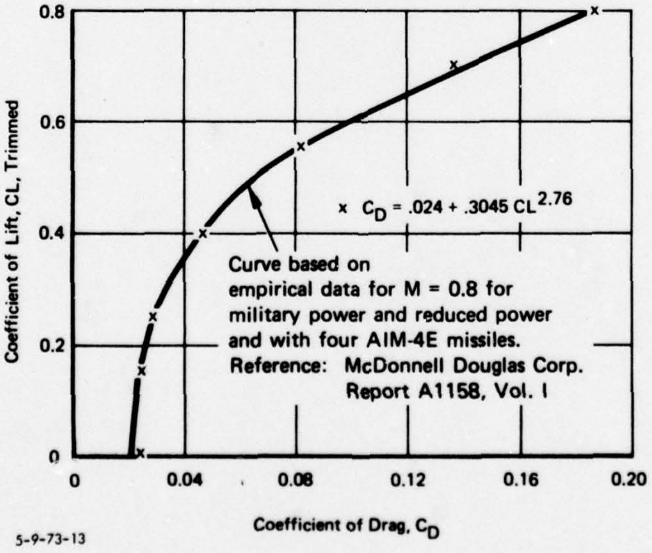

Figure 4. Approximation to C_D Versus CL Curve, F-4E/J

COMPARISON WITH DATA FROM SIMULATION OF FLIGHT PATH

To illustrate the accuracy with which ANGLE can determine aircraft attitude, the program was used to compute attitude for a flight path that was generated by AFATL, Eglin AFB, Florida. AFATL generated the flight path with a computer program that performs a numerical integration of the equations of motion. The data provided by AFATL include the aircraft attitude and angle of attack as well as the position at each instant of time. Data are presented at 0.2-second intervals.

The position data were read and processed by ANGLE; the aircraft attitudes computed by ANGLE, and the attitudes that had been used by the AFATL program to compute the position data, were printed out for comparison. These results are given in Table 2. Attitude values from the AFATL data are labeled ______IN, and the corresponding values computed by ANGLE are labeled _____OUT. The column of integers at the far right is the number of iterations required in the T → L → DP → ALPH → T cycle.

The flight path used in the comparison is typical of the F-4 flight paths to be used in the HITVAL test program. The aircraft approaches in level flight, rolls to the left, and pulls down into a 45-degree dive. It then rolls back to wings level, continues the dive, and reaches an ordnance release point at an altitude of 1,061 meters (corresponding to a breakaway distance of 1.5 km) at a speed of 257 meters per second (500 knots). At the release point, the aircraft begins to pull out of the dive, developing a normal acceleration of 4 to 5 g's. Then the aircraft turns to the left again and leaves the area in a climb.

From Table 2, it is apparent that the attitude and angle of attack computed by ANGLE and the corresponding values from AFATL usually agree to within 10 mrad (0.6 degree). The poorest agreement is in ROLL, where differences of about 50 mrad (3 degrees) sometimes occur for 0.2 to 0.4 second. As noted in the Introduction, noise or other inaccuracies in the aircraft position data will degrade the accuracy of the computed attitude.

Table 2. *Example of Program Printout*

```
YAW IN   YAW OUT   PITCH IN  PITCH OUT  ROLL IN  ROLL OUT   ALPH IN  ALPH OUT

 -.78     -.79       .03       .03       0.00      .00       .03      .03           1
 -.79     -.79       .03       .03       0.00     -.01       .03      .03           1
 -.79     -.78       .03       .03      -0.00     -.02       .03      .03           1
 -.79     -.79       .03       .03      -0.00     -.00       .03      .03           1
 -.78     -.79       .03       .03       0.00      .00       .03      .03           1
 -.79     -.79       .03       .03       0.00      .01       .03      .03           1
 -.79     -.79       .03       .03      -0.00      .02       .03      .03           1
 -.79     -.79       .03       .03      -0.00      .02       .03      .03           1
 -.78     -.79       .03       .03       0.00      .00       .03      .03           1
 -.79     -.79       .03       .03       0.00     -.01       .03      .03           1
 -.79     -.79       .03       .03      -0.00     -.01       .03      .03           1
 -.79     -.79       .03       .03      -0.00     -.01       .03      .03           1
 -.78     -.79       .03       .03       0.00     -.01       .03      .03           1
 -.79     -.79       .03       .03       0.00      .01       .03      .03           1
 -.79     -.79       .03       .03      -0.00      .01       .03      .03           1
 -.79     -.79       .03       .03      -0.00      .02       .03      .03           1
 -.78     -.79       .03       .03       0.00     -.00       .03      .03           1
 -.79     -.79       .03       .03       0.00     -.01       .03      .03           1
 -.79     -.79       .03       .03      -0.00     -.01       .03      .03           1
 -.79     -.79       .03       .03      -0.00     -.00       .03      .03           1
 -.78     -.79       .03       .03       0.00     -.00       .03      .03           1
 -.79     -.79       .03       .03       0.00     -.00       .03      .03           1
 -.79     -.79       .03       .03      -0.00      .00       .03      .03           1
 -.79     -.79       .03       .03      -0.00     -.01       .03      .03           1
 -.78     -.79       .03       .03       0.00      .00       .03      .03           1
 -.79     -.79       .03       .03       0.00      .01       .03      .03           1
 -.79     -.79       .03       .03      -0.00      .01       .03      .03           1
 -.79     -.79       .03       .03       0.00      .01       .03      .03           1
 -.78     -.79       .03       .03      -0.00     -.01       .03      .03           1
 -.79     -.78       .03       .03       0.00     -.04       .03      .03           1
 -.78     -.78       .03       .04       -.04     -.11       .03      .04           1
 -.78     -.78       .04       .04       -.15     -.20       .04      .04           1
 -.77     -.77       .05       .05       -.30     -.33       .05      .05           2
 -.76     -.76       .05       .05       -.46     -.47       .05      .05           2
 -.74     -.74       .06       .06       -.62     -.63       .06      .06           2
 -.72     -.72       .06       .06       -.78     -.79       .07      .07           2
 -.70     -.70       .06       .05       -.93     -.95       .07      .07           2
 -.68     -.68       .05       .05      -1.09    -1.10       .08      .08           2
 -.66     -.66       .04       .04      -1.25    -1.25       .09      .09           1
 -.64     -.65       .03       .03      -1.41    -1.41       .09      .09           1
 -.63     -.63       .01       .01      -1.57    -1.56       .10      .09           1
 -.62     -.62      -.01      -.01      -1.72    -1.71       .10      .10           1
 -.61     -.61      -.03      -.03      -1.88    -1.87       .10      .10           1
 -.60     -.60      -.06      -.05      -2.04    -2.02       .10      .10           1
 -.60     -.60      -.08      -.08      -2.19    -2.16       .10      .10           1
 -.60     -.59      -.10      -.10      -2.34    -2.29       .09      .10           1
 -.60     -.59      -.12      -.12      -2.42    -2.38       .10      .10           1
 -.59     -.58      -.13      -.13      -2.44    -2.42       .10      .10           1
 -.58     -.58      -.15      -.15      -2.41    -2.44       .10      .10           1
 -.57     -.57      -.16      -.16      -2.41    -2.43       .10      .10           1
 -.56     -.56      -.17      -.17      -2.41    -2.41       .10      .10           1
 -.55     -.55      -.19      -.19      -2.41    -2.41       .10      .10           1
 -.55     -.55      -.20      -.20      -2.41    -2.41       .09      .10           1
 -.54     -.54      -.21      -.21      -2.41    -2.41       .09      .10           1
 -.53     -.53      -.22      -.22      -2.40    -2.40       .10      .10           1
 -.52     -.52      -.24      -.24      -2.40    -2.40       .10      .10           1
 -.51     -.51      -.25      -.25      -2.40    -2.40       .09      .10           1
 -.50     -.50      -.26      -.26      -2.39    -2.39       .10      .10           1
 -.49     -.49      -.28      -.28      -2.39    -2.39       .10      .10           1
 -.49     -.49      -.29      -.29      -2.39    -2.39       .09      .10           1
 -.48     -.48      -.30      -.30      -2.39    -2.39       .10      .10           1
 -.47     -.47      -.31      -.32      -2.38    -2.39       .10      .10           1
 -.46     -.46      -.33      -.33      -2.38    -2.38       .10      .10           1
 -.45     -.45      -.34      -.34      -2.38    -2.38       .10      .10           1
 -.44     -.44      -.35      -.35      -2.37    -2.37       .10      .10           1
 -.43     -.43      -.37      -.37      -2.37    -2.37       .10      .10           1
```

Table 2 (Continued)

YAW IN	YAW OUT	PITCH IN	PITCH OUT	ROLL IN	ROLL OUT	ALPH IN	ALPH OUT	
-.42	-.42	-.38	-.38	-2.37	-2.37	.09	.10	1
-.41	-.41	-.39	-.39	-2.36	-2.36	.09	.10	1
-.41	-.40	-.40	-.40	-2.36	-2.36	.09	.10	1
-.40	-.39	-.42	-.42	-2.35	-2.36	.09	.10	1
-.39	-.39	-.43	-.43	-2.35	-2.35	.09	.10	1
-.38	-.38	-.44	-.44	-2.35	-2.35	.09	.10	1
-.37	-.37	-.45	-.45	-2.34	-2.34	.09	.10	1
-.36	-.36	-.46	-.46	-2.34	-2.34	.09	.10	1
-.35	-.35	-.48	-.48	-2.33	-2.33	.09	.10	1
-.34	-.34	-.49	-.49	-2.33	-2.32	.09	.10	1
-.33	-.33	-.50	-.50	-2.32	-2.33	.09	.10	1
-.32	-.32	-.51	-.51	-2.32	-2.32	.09	.10	1
-.31	-.31	-.52	-.52	-2.31	-2.31	.09	.09	1
-.30	-.30	-.53	-.54	-2.31	-2.31	.09	.10	1
-.29	-.29	-.55	-.55	-2.30	-2.30	.09	.10	1
-.27	-.27	-.56	-.56	-2.29	-2.30	.09	.09	1
-.26	-.26	-.57	-.57	-2.29	-2.29	.09	.09	1
-.25	-.25	-.58	-.58	-2.28	-2.29	.09	.09	1
-.24	-.24	-.59	-.59	-2.28	-2.28	.09	.09	1
-.23	-.23	-.60	-.60	-2.27	-2.27	.09	.09	1
-.22	-.22	-.61	-.62	-2.27	-2.26	.09	.09	1
-.21	-.21	-.63	-.63	-2.26	-2.26	.09	.09	1
-.20	-.20	-.64	-.64	-2.25	-2.25	.09	.09	1
-.18	-.18	-.65	-.65	-2.24	-2.25	.09	.09	1
-.17	-.17	-.66	-.66	-2.23	-2.23	.09	.09	1
-.16	-.16	-.67	-.67	-2.23	-2.22	.09	.09	1
-.15	-.15	-.68	-.68	-2.22	-2.21	.09	.09	1
-.13	-.13	-.69	-.69	-2.21	-2.21	.09	.09	1
-.12	-.12	-.70	-.70	-2.20	-2.20	.09	.09	1
-.11	-.11	-.71	-.71	-2.19	-2.20	.09	.09	1
-.10	-.10	-.72	-.72	-2.19	-2.18	.09	.09	1
-.08	-.08	-.73	-.73	-2.18	-2.18	.09	.09	1
-.07	-.07	-.74	-.74	-2.17	-2.16	.09	.09	1
-.06	-.06	-.75	-.75	-2.15	-2.16	.09	.09	1
-.04	-.04	-.76	-.76	-2.15	-2.14	.09	.09	1
-.03	-.03	-.77	-.77	-2.14	-2.14	.09	.09	1
-.01	-.01	-.78	-.78	-2.12	-2.12	.09	.09	1
0.00	.00	-.79	-.79	-2.11	-2.11	.09	.09	1
.02	.01	-.80	-.79	-2.09	-2.11	.09	.09	1
.03	.02	-.80	-.80	-2.10	-2.10	.09	.08	2
.03	.02	-.81	-.80	-2.10	-2.09	.08	.07	2
.02	.02	-.80	-.80	-2.04	-2.04	.06	.06	2
0.00	.02	-.79	-.80	-1.92	-1.96	.04	.05	2
-0.00	.01	-.79	-.79	-1.76	-1.83	.03	.04	2
.01	.01	-.79	-.79	-1.60	-1.65	.03	.03	2
.01	.01	-.79	-.79	-1.44	-1.44	.03	.03	1
.02	.01	-.78	-.79	-1.28	-1.26	.03	.02	1
.02	.02	-.78	-.78	-1.12	-1.11	.03	.03	1
.02	.02	-.78	-.78	-.96	-.96	.03	.03	1
.02	.02	-.78	-.78	-.80	-.80	.03	.03	1
.02	.02	-.77	-.78	-.65	-.65	.03	.03	1
.02	.02	-.77	-.77	-.49	-.49	.03	.03	1
.01	.02	-.77	-.77	-.34	-.35	.03	.03	1
.01	.01	-.77	-.77	-.18	-.22	.03	.03	1
.01	.01	-.77	-.77	-.06	-.12	.03	.02	1
.01	.01	-.76	-.77	0.00	-.04	.03	.02	1
0.00	.00	-.77	-.77	.01	.02	.02	.02	1
.01	.00	-.77	-.77	-0.00	.03	.02	.02	1
.01	.00	-.77	-.77	.01	.03	.02	.02	1
0.00	.00	-.77	-.77	.01	.00	.02	.02	1
0.00	.01	-.77	-.77	-0.00	-.02	.02	.02	1
0.00	.00	-.77	-.77	.01	.01	.02	.02	1
.01	.00	-.77	-.77	0.00	.01	.02	.02	1
.01	.00	-.77	-.77	0.00	.02	.02	.02	1
.01	.00	-.77	-.77	-0.00	-.01	.02	.02	1
0.00	.01	-.77	-.77	-0.00	-.00	.02	.02	1
0.00	.00	-.77	-.78	0.00	-.00	.02	.01	1
0.00	.01	-.77	-.78	0.00	-.01	.02	.01	1
.01	.02	-.77	-.78	.01	.02	.02	.01	1
.01	.00	-.77	-.78	0.00	.02	.02	.01	1

Table 2 (Continued)

YAW IN	YAW OUT	PITCH IN	PITCH OUT	ROLL IN	ROLL OUT	ALPH IN	ALPH OUT	
.01	.00	-.77	-.78	0.00	.00	.02	.01	1
0.00	.01	-.77	-.78	0.00	-.01	.02	.01	1
0.00	.00	-.77	-.78	-0.00	-.01	.02	.01	1
0.00	.00	-.77	-.78	.01	.01	.02	.01	1
.01	.00	-.77	-.78	0.00	-.01	.02	.01	1
0.00	.00	-.77	-.78	0.00	.02	.02	.01	1
0.00	.00	-.77	-.78	.01	.01	.02	.01	1
0.00	.00	-.78	-.78	-0.00	-.01	.01	.01	1
0.00	.00	-.77	-.78	.01	-.00	.02	.01	1
0.00	.00	-.77	-.78	-0.00	.03	.02	.01	1
0.00	.00	-.78	-.78	0.00	.01	.01	.01	1
0.00	.00	-.78	-.78	-0.00	-.01	.01	.01	1
0.00	.00	-.78	-.78	0.00	.01	.01	.01	1
0.00	.00	-.78	-.78	0.00	-.01	.02	.01	1
0.00	.00	-.77	-.78	0.00	-.01	.01	.01	1
0.00	.00	-.77	-.78	-0.00	.00	.02	.01	1
0.00	.00	-.77	-.78	0.00	.02	.01	.01	1
0.00	.00	-.78	-.78	0.00	-.00	.01	.01	1
0.00	.00	-.78	-.78	0.00	-.00	.01	.01	1
0.00	.00	-.78	-.78	-0.00	.00	.01	.01	1
0.00	.00	-.78	-.78	0.00	-.02	.01	.01	1
0.00	.00	-.78	-.78	0.00	.00	.01	.01	1
0.00	.00	-.78	-.78	0.00	.01	.01	.01	1
0.00	.00	-.78	-.78	-0.00	.01	.01	.01	1
0.00	.00	-.78	-.78	0.00	-.01	.01	.01	1
0.00	.00	-.78	-.78	0.00	.01	.01	.01	1
0.00	.00	-.78	-.77	0.00	.01	.01	.02	1
0.00	.00	-.78	-.77	-0.00	-.00	.01	.02	2
0.00	.00	-.77	-.76	.01	.01	.02	.03	2
0.00	.00	-.75	-.74	.01	.01	.04	.05	2
0.00	.00	-.71	-.72	.01	.01	.07	.06	2
0.00	.00	-.68	-.69	.01	.00	.09	.08	2
0.00	.00	-.66	-.67	0.00	.00	.10	.09	2
0.00	.00	-.65	-.65	0.00	.00	.10	.10	2
0.00	.00	-.63	-.64	0.00	.00	.10	.10	1
0.00	.00	-.62	-.62	0.00	.00	.10	.10	1
0.00	.00	-.61	-.61	.01	.01	.10	.10	1
0.00	.00	-.59	-.60	.01	.01	.10	.10	1
0.00	.00	-.58	-.58	0.00	.01	.10	.09	1
0.00	.00	-.57	-.57	0.00	.00	.09	.09	1
0.00	.00	-.56	-.56	0.00	.00	.09	.09	1
0.00	.00	-.55	-.55	0.00	.00	.09	.09	1
0.00	.00	-.53	-.54	.01	.01	.09	.09	1
0.00	.00	-.52	-.53	.01	.01	.09	.09	1
0.00	.00	-.51	-.51	0.00	.00	.09	.09	1
0.00	.00	-.50	-.50	0.00	.00	.09	.09	1
0.00	.00	-.49	-.49	0.00	.00	.09	.09	1
0.00	.00	-.48	-.48	0.00	.00	.09	.09	1
0.00	.00	-.46	-.47	.01	.01	.09	.09	1
0.00	.00	-.45	-.45	.01	.01	.09	.09	1
0.00	.00	-.44	-.44	.01	.01	.09	.09	1
0.00	.00	-.43	-.43	0.00	.00	.09	.09	1
0.00	.00	-.42	-.42	0.00	.00	.09	.08	1
0.00	.00	-.41	-.41	0.00	.01	.08	.08	1
0.00	.00	-.40	-.40	0.00	.00	.08	.08	1
0.00	.00	-.38	-.38	.01	.00	.08	.08	1
0.00	.00	-.37	-.37	.01	.00	.08	.08	1
0.00	.00	-.36	-.36	0.00	.00	.08	.08	1
0.00	.00	-.35	-.35	0.00	.00	.08	.08	1
0.00	.00	-.34	-.34	0.00	.01	.08	.08	1
0.00	.00	-.33	-.33	0.00	.01	.08	.08	1
0.00	.00	-.32	-.32	0.00	.00	.08	.08	1
0.00	.00	-.31	-.31	0.00	.01	.08	.08	1
0.00	.00	-.29	-.29	0.00	.00	.08	.08	1
0.00	.00	-.28	-.28	0.00	.00	.08	.08	1
0.00	.00	-.27	-.27	0.00	.00	.08	.08	1
0.00	.00	-.26	-.26	0.00	.01	.08	.08	1
0.00	.00	-.25	-.25	0.00	.00	.08	.08	1
0.00	.00	-.24	-.24	0.00	.00	.08	.08	1
0.00	.00	-.23	-.23	.01	.00	.08	.08	1

Table 2 (Continued)

YAW IN	YAW OUT	PITCH IN	PITCH OUT	ROLL IN	ROLL OUT	ALPH IN	ALPH OUT	
0.00	.00	-.22	-.22	0.00	.00	.07	.08	1
0.00	.00	-.21	-.21	0.00	.00	.07	.08	1
0.00	.00	-.20	-.19	0.00	.01	.07	.08	1
0.00	.00	-.19	-.18	0.00	.00	.07	.08	1
0.00	.00	-.18	-.17	.01	.00	.07	.08	1
0.00	.00	-.16	-.16	0.00	.00	.07	.08	1
0.00	.00	-.15	-.15	0.00	.00	.07	.07	1
0.00	.00	-.14	-.14	.01	.00	.07	.07	1
0.00	.00	-.13	-.13	0.00	.01	.07	.07	1
0.00	.00	-.12	-.12	0.00	.00	.07	.07	1
0.00	.00	-.11	-.11	0.00	.00	.07	.07	1
0.00	.00	-.10	-.10	0.00	.00	.07	.07	1
0.00	.00	-.09	-.09	.01	.00	.07	.07	1
0.00	.00	-.08	-.08	0.00	.00	.07	.07	1
0.00	.00	-.07	-.06	0.00	.00	.07	.07	1
-0.00	.00	-.06	-.05	-0.00	.00	.07	.07	1
-0.00	.00	-.05	-.04	0.00	-.00	.07	.07	1
-0.00	.00	-.04	-.03	0.00	.00	.07	.07	1
0.00	.00	-.03	-.02	.01	.00	.07	.07	1
0.00	-.00	-.01	-.01	.01	.00	.07	.07	1
0.00	-.00	-0.00	-.00	0.00	.00	.07	.07	1
0.00	-.00	.01	.01	0.00	.01	.07	.07	1
0.00	-.00	.02	.02	-.01	.00	.07	.07	1
-0.00	.00	.03	.03	.02	-.01	.07	.07	1
0.00	.00	.04	.04	-.01	-.06	.07	.07	1
.01	.01	.05	.05	-.11	-.14	.06	.07	1
.02	.02	.06	.06	-.26	-.25	.06	.07	1
.03	.04	.06	.07	-.42	-.40	.06	.07	1
.05	.05	.07	.07	-.58	-.55	.06	.07	1
.06	.07	.07	.07	-.74	-.69	.06	.07	1
.08	.08	.07	.08	-.84	-.80	.06	.07	1
.09	.09	.07	.08	-.89	-.86	.06	.07	1
.10	.11	.08	.08	-.88	-.89	.06	.07	1
.11	.12	.08	.09	-.88	-.89	.06	.07	1
.12	.13	.09	.09	-.88	-.89	.06	.07	1
.13	.14	.09	.10	-.88	-.89	.06	.07	1
.14	.15	.10	.10	-.88	-.88	.06	.07	1
.15	.16	.10	.11	-.88	-.88	.06	.07	1
.16	.17	.11	.11	-.89	-.89	.06	.07	1
.17	.18	.12	.12	-.88	-.89	.06	.06	1
.19	.19	.12	.12	-.89	-.89	.06	.06	1
.20	.20	.13	.13	-.89	-.89	.06	.06	1
.21	.21	.13	.14	-.89	-.89	.06	.06	1
.22	.22	.14	.14	-.89	-.89	.06	.06	1
.23	.23	.14	.15	-.89	-.89	.06	.06	1
.24	.24	.15	.15	-.89	-.89	.06	.06	1
.25	.25	.15	.16	-.89	-.90	.06	.06	1
.26	.26	.16	.16	-.90	-.90	.06	.06	1
.27	.27	.16	.17	-.90	-.90	.06	.06	1
.28	.28	.17	.17	-.90	-.90	.06	.06	1
.29	.29	.17	.18	-.90	-.90	.06	.06	1
.30	.30	.18	.18	-.90	-.90	.06	.06	1
.31	.31	.18	.19	-.90	-.90	.06	.06	1
.32	.32	.19	.19	-.90	-.91	.06	.06	1
.33	.34	.19	.20	-.91	-.91	.06	.06	1
.34	.35	.20	.20	-.91	-.91	.06	.06	1
.35	.36	.20	.21	-.91	-.91	.06	.06	1
.36	.37	.21	.21	-.91	-.91	.06	.06	1
.37	.38	.21	.22	-.92	-.92	.06	.06	1
.39	.39	.22	.22	-.92	-.92	.06	.06	1
.40	.40	.22	.23	-.92	-.92	.06	.06	1
.41	.41	.23	.23	-.92	-.92	.06	.06	1
.42	.42	.23	.24	-.92	-.93	.06	.06	1
.43	.43	.24	.24	-.93	-.92	.05	.06	1
.44	.44	.24	.25	-.93	-.93	.06	.06	1
.45	.45	.25	.25	-.93	-.93	.06	.06	1

Table 2 (Continued)

YAW IN	YAW OUT	PITCH IN	PITCH OUT	ROLL IN	ROLL OUT	ALPH IN	ALPH OUT	
.46	.46	.25	.25	-.94	-.94	.06	.06	1
.47	.47	.26	.26	-.94	-.94	.06	.06	1
.48	.48	.26	.26	-.94	-.94	.05	.06	1
.49	.50	.27	.27	-.94	-.94	.05	.06	1
.50	.51	.27	.27	-.94	-.95	.05	.06	1
.51	.52	.28	.28	-.95	-.95	.06	.06	1
.53	.53	.28	.28	-.95	-.95	.06	.06	1
.54	.54	.29	.29	-.95	-.95	.06	.06	1
.55	.55	.29	.29	-.96	-.96	.05	.06	1
.56	.56	.29	.30	-.96	-.96	.05	.06	1
.57	.57	.30	.30	-.96	-.96	.05	.06	1
.58	.58	.30	.31	-.97	-.97	.06	.06	1
.59	.59	.31	.31	-.97	-.97	.06	.06	1
.60	.60	.31	.31	-.97	-.97	.06	.06	1
.61	.61	.32	.32	-.98	-.98	.05	.06	1
.62	.63	.32	.32	-.98	-.98	.05	.06	1
.63	.64	.33	.33	-.98	-.98	.05	.06	1
.65	.65	.33	.33	-.99	-.98	.06	.06	1
.66	.66	.33	.34	-.99	-.99	.06	.06	1
.67	.67	.34	.34	-.99	-.99	.06	.06	1
.68	.68	.34	.34	-1.00	-1.00	.05	.06	1
.69	.69	.34	.35	-1.00	-1.00	.05	.06	1
.70	.70	.35	.35	-1.00	-1.01	.05	.06	1
.71	.72	.35	.36	-1.01	-1.01	.06	.06	1
.73	.73	.36	.36	-1.01	-1.01	.06	.06	1
.74	.74	.36	.36	-1.01	-1.02	.06	.06	1
.75	.75	.37	.37	-1.02	-1.02	.05	.06	1
.76	.76	.37	.37	-1.02	-1.02	.05	.06	1
.77	.77	.37	.37	-1.03	-1.03	.05	.06	1
.78	.78	.38	.38	-1.03	-1.03	.06	.06	1
.79	.80	.38	.38	-1.03	-1.04	.06	.06	1
.81	.81	.38	.39	-1.04	-1.04	.05	.06	1
.82	.82	.39	.39	-1.04	-1.05	.05	.06	1
.83	.83	.39	.39	-1.05	-1.05	.05	.06	1
.84	.84	.40	.40	-1.05	-1.05	.06	.06	1
.85	.85	.40	.40	-1.06	-1.06	.06	.06	1
.86	.87	.40	.40	-1.06	-1.06	.05	.06	1
.88	.88	.41	.41	-1.07	-1.07	.05	.06	1
.89	.89	.41	.41	-1.07	-1.07	.06	.06	1
.90	.90	.41	.41	-1.07	-1.08	.06	.06	1
.91	.92	.42	.42	-1.08	-1.08	.06	.06	1
.93	.93	.42	.42	-1.08	-1.08	.05	.06	1
.94	.94	.42	.42	-1.09	-1.09	.06	.06	1
.95	.95	.43	.43	-1.09	-1.10	.06	.06	1
.96	.96	.43	.43	-1.10	-1.10	.06	.06	1
.97	.98	.43	.43	-1.11	-1.11	.06	.06	1
.99	.99	.43	.44	-1.11	-1.11	.06	.06	1
1.00	1.00	.44	.44	-1.12	-1.12	.06	.06	1
1.01	1.01	.44	.44	-1.12	-1.12	.06	.06	1
1.02	1.03	.44	.44	-1.13	-1.13	.06	.06	1
1.04	1.04	.45	.45	-1.13	-1.13	.06	.06	1
1.05	1.05	.45	.45	-1.14	-1.13	.06	.06	1
1.06	1.06	.45	.45	-1.14	-1.14	.06	.06	1
1.07	1.08	.45	.45	-1.15	-1.14	.06	.06	1
1.09	1.09	.46	.46	-1.15	-1.15	.06	.06	1
1.10	1.10	.46	.46	-1.16	-1.16	.06	.06	1
1.11	1.12	.46	.46	-1.17	-1.17	.06	.06	1
1.13	1.13	.46	.46	-1.17	-1.17	.06	.06	1
1.14	1.14	.47	.47	-1.17	-1.18	.06	.06	1
1.15	1.15	.47	.47	-1.18	-1.18	.06	.06	1
1.16	1.17	.47	.47	-1.19	-1.19	.06	.06	1
1.18	1.18	.47	.47	-1.19	-1.19	.06	.06	1
1.19	1.19	.47	.47	-1.20	-1.20	.06	.06	1
1.20	1.21	.48	.48	-1.20	-1.21	.06	.06	1
1.22	1.22	.48	.48	-1.21	-1.21	.06	.06	1
1.23	1.23	.48	.48	-1.21	-1.22	.06	.06	1

Table 2 (Continued)

YAW IN	YAW OUT	PITCH IN	PITCH OUT	ROLL IN	ROLL OUT	ALPH IN	ALPH OUT	
1.24	1.25	.48	.48	-1.22	-1.22	.06	.06	1
1.26	1.26	.48	.48	-1.23	-1.23	.06	.06	1
1.27	1.27	.48	.49	-1.23	-1.23	.06	.06	1
1.28	1.29	.49	.49	-1.24	-1.24	.06	.06	1
1.30	1.30	.49	.49	-1.25	-1.25	.06	.06	1
1.31	1.31	.49	.49	-1.25	-1.25	.06	.06	1
1.32	1.33	.49	.49	-1.26	-1.26	.06	.06	1
1.34	1.34	.49	.49	-1.26	-1.26	.06	.06	1
1.35	1.35	.49	.49	-1.27	-1.27	.06	.06	1
1.37	1.37	.49	.49	-1.27	-1.28	.06	.06	1
1.38	1.38	.49	.50	-1.28	-1.29	.06	.06	1
1.39	1.40	.50	.50	-1.29	-1.29	.06	.06	1
1.41	1.41	.50	.50	-1.29	-1.30	.06	.06	1
1.42	1.42	.50	.50	-1.30	-1.30	.06	.06	1
1.43	1.44	.50	.50	-1.30	-1.31	.06	.06	1
1.45	1.45	.50	.50	-1.32	-1.32	.06	.06	1
1.46	1.46	.50	.50	-1.32	-1.32	.06	.06	1
1.48	1.48	.50	.50	-1.33	-1.33	.06	.06	1
1.49	1.49	.50	.50	-1.33	-1.34	.06	.06	1
1.50	1.51	.50	.50	-1.34	-1.34	.06	.06	1
1.52	1.52	.50	.50	-1.35	-1.35	.06	.06	1
1.53	1.53	.50	.50	-1.35	-1.36	.06	.06	1
1.54	1.55	.50	.50	-1.36	-1.37	.06	.06	1
1.56	1.56	.50	.50	-1.37	-1.37	.06	.06	1
1.57	1.57	.50	.50	-1.37	-1.35	.06	.06	1
1.58	1.58	.50	.50	-1.36	-1.32	.06	.06	1
1.59	1.59	.50	.51	-1.27	-1.26	.05	.05	1
1.59	1.59	.51	.51	-1.12	-1.15	.05	.05	1
1.59	1.60	.52	.52	-.97	-1.01	.04	.05	1
1.59	1.60	.52	.52	-.81	-.85	.04	.04	1
1.59	1.59	.53	.53	-.65	-.68	.04	.04	1
1.59	1.59	.53	.53	-.49	-.52	.03	.03	1
1.58	1.59	.53	.53	-.33	-.38	.03	.03	1
1.58	1.58	.53	.53	-.17	-.23	.02	.03	1
1.58	1.58	.53	.53	-.05	-.12	.02	.02	1
1.58	1.58	.53	.53	0.00	-.02	.02	.02	1
1.58	1.58	.53	.53	-0.00	.03	.01	.01	1
1.58	1.58	.52	.53	-0.00	.04	.01	.01	1
1.58	1.58	.52	.53	0.00	.02	.01	.01	1
1.58	1.58	.52	.53	0.00	-.01	.01	.01	1
1.58	1.58	.52	.53	-0.00	-.00	.01	.01	1
1.58	1.58	.52	.53	-0.00	.00	.01	.01	1
1.58	1.58	.52	.53	0.00	.01	.01	.01	1
1.58	1.58	.52	.53	0.00	.01	.01	.01	1
1.58	1.58	.52	.53	-0.00	.01	.01	.01	1
1.58	1.58	.52	.53	-0.00	-.02	.01	.01	1
1.58	1.58	.52	.53	0.00	-.01	.01	.01	1
1.58	1.58	.52	.53	0.00	-.01	.01	.01	1
1.58	1.58	.52	.53	-0.00	.00	.01	.01	1
1.58	1.58	.52	.53	0.00	.01	.01	.01	1
1.58	1.58	.52	.53	0.00	-.00	.01	.01	1
1.58	1.58	.52	.53	0.00	.00	.01	.01	1
1.58	1.58	.52	.53	-0.00	-.01	.01	.01	1
1.58	1.58	.52	.53	-0.00	.00	.01	.01	1
1.58	1.58	.52	.53	0.00	-.00	.01	.01	1
1.58	1.58	.52	.53	0.00	.00	.01	.01	1
1.58	1.58	.52	.53	-0.00	.01	.01	.01	1
1.58	1.58	.52	.53	-0.00	-.00	.01	.01	1
1.58	1.58	.52	.53	0.00	.01	.01	.01	1
1.58	1.59	.52	.53	0.00	-.00	.01	.01	1
1.58	1.58	.52	.53	-0.00	.00	.01	.01	1
1.58	1.58	.52	.53	-0.00	-.01	.01	.01	1
1.58	1.58	.52	.53	0.00	.00	.01	.01	1
1.58	1.58	.52	.53	0.00	.01	.01	.01	1
1.58	1.58	.52	.53	-0.00	-.00	.01	.01	1

PROGRAM LISTING

```
      PROGRAM ANGLE(INPUT, OUTPUT, TAPE5)
      DIMENSION NTITLE(24),XI(1000,3),TI(1000),AZ(1000),EL(1000),ROL(100
     10),AL(1000)
      DIMENSION XDI(3),XDDI(3),B1(1000,3),B2(1000,3)
      DIMENSION XDZZ(3),XDDZZ(3),CLINE(3),ANX(3),HL(3),W(3)
      DIMENSION XD(1000,3),XDD(1000,3)
      NT=5
C     THE FOLLOWING DATA IS FOR THE F-4 AND FOR THE PARTICULAR FLIGHT
C     PATH DATA USED IN THE DEMONSTRATION RUN.
C     WT IS AIRCRAFT WEIGHT. S IS REFERENCE AREA IN SQUARE METERS. TA IS
C     THRUST ANGLE ABOVE THE LONGITUDINAL AXIS OF THE AIRCRAFT, AND ALTB
C     IS THE ALTITUDE BASE,I.E. THE ELEVATION ABOVE SEA LEVEL OF THE
C     ORIGIN OF THE COORDINATE SYSTEM THAT IS USED TO SPECIFY THE FLIGHT
C     PATH.
      DATA WT,S,TA,ALTB/14272.,49.2,.005,0./
      DP=.22*WT
      ALPHP=.05
      ROLLP=0.
      G=9.8
      WOG=WT/G
      READ(NT,100)
  100 FORMAT(//////////)
C     THE DO 160 LOOP IS SET UP TO READ A PARTICULAR TAPE FORMAT.
C     THIS MUST BE CHANGED TO CORRESPOND TO THE FORMAT OF THE INPUT TAPE
C     OF FLIGHT PATH DATA BEING USED.
      KPTS=0
      DO 160 I=1,1000
      KPTS=KPTS+1
      READ(NT,102) TI(I),(XI(I,J),J=1,3),AZ(I),EL(I),ROL(I),AL(I)
C     NOTE THAT AZ, EL, ROL, AND AL ARE THE YAW, PITCH, AND ANGLE OF
C     ATTACK OF THE AIRCRAFT.  THESE DATA ARE AVAILABLE FOR THE
C     PARTICULAR FLIGHT PATH BEING USED AND ARE READ HERE SO THAT THEY
C     CAN BE COMPARED TO THE VALUES COMPUTED WITH THIS PROGRAM.
  102 FORMAT(F5.1,3F10.2,75X,4F5.2)
      IF (EOF,NT) 150,160
  160 CONTINUE
  150 KPTS=KPTS-1
C     NOTE THAT THE PROGRAM IS NOW SET UP TO READ UP TO 1000 DATA POINTS
C     .  THE AMOUNT OF MEMORY COULD BE GREATLY REDUCED BY READING INPUT
C     AS IT IS NEEDED.  TRAJ COULD BE DISCARDED AND FIT3 COULD BE CALLED
C     INSIDE THE DO 20 LOOP.
      T1=TI(2)-TI(1)
      T2=TI(3)-TI(2)
      T=(T2+T1)/2.
      DO 11 I=1,3
      XDI(I)=(XI(2,I)-XI(1,I))/T1
      Z=(XI(3,I)-XI(2,I))/T2
      XDDI(I)=(Z-XDI(I))/T
   11 XDI(I)=(Z+XDI(I))/2.
C     IF VELOCITY AND ACCELERATION DATA ARE AVAILABLE AS INPUT IT SHOULD
C     BE READ AND THE CALL ON SUBROUTINE TRAJ SHOULD BE SKIPPED.  TRAJ
C     CALLS FIT3 AND COMPUTES VELOCITY AND ACCELERATION.
      CALL TRAJ(KPTS,XI,TI,XDI,XDDI,XD,XDD,B1,B2)
      PRINT 106
C     THIS HEADING IS FOR THE CHECKOUT RUNS ONLY.
  106 FORMAT(//,15X,6HYAW IN,3X,7HYAW OUT,3X,8HPITCH IN,2X,9HPITCH OUT,
     12X,7HROLL IN,2X,8HROLL OUT,3X,7HALPH IN,2X,8HALPH OUT,/)
```

```
      MPTS=NPTS-3
      DO 20 I=6,MPTS
      NITER=0
      DO 12 J=1,3
      XDZZ(J)=XD(I,J)
   12 XDDZZ(J)=XDD(I,J)
      VZZ=SQRT(XDZZ(1)**2+XDZZ(2)**2+XDZZ(3)**2)
      XDDZZ(3)=XDDZZ(3)+9.8
      ALNG=(XDZZ(1)*XDDZZ(1)+XDZZ(2)*XDDZZ(2)+XDZZ(3)*XDDZZ(3))/VZZ
      DO 14 J=1,3
   14 ANX(J)=XDDZZ(J)-XDZZ(J)*ALNG/VZZ
      ANOR=SQRT(ANX(1)**2+ANX(2)**2+ANX(3)**2)
   15 ALPHT=ALPHP+TA
      T=(ALNG*WOG+DP)/COS(ALPHT)
      L=ANOR*WOG-T*SIN(ALPHT)
      QS=QUE(XT(I,3)+ALT3,VZZ)*S
      CL=L/QS
      IF(CL.LT.0.) GO TO 17
C     THE FOLLOWING CALCULATIONS OF DP AND ALPH ARE FOR THE F-4.  THEY
C     MUST BE CHANGED FOR OTHER AIRCRAFT.
      DP=QS*(.024+.3045*CL**2.76)
   17 CALL ALPHA(CL,ALPH,IFLAG,JFLAG)
      IF(IFLAG+JFLAG.GT.0)GO TO 16
      NITER=NITER+1
      IF(ABS(ALPH-ALPHP).LT..005) GO TO 18
      ALPHP=ALPH
      IF (NITER.LE.6) GO TO 15
      PRINT 107
  107 FORMAT(10X,*NITER REACHED SEVEN.*)
   18 ALPHP=ALPH
      VTANA=VZZ*TAN(ALPH)/ANOR
      DO 19 J=1,3
   19 CLINE(J)=XDZZ(J)+VTANA*ANX(J)
      CALL THEPHI(CLINE(1),CLINE(2),CLINE(3),R,GR,YAW,PITCH)
      FAC=GR
      HL(1)=CLINE(2)/FAC
      IF(HL(1).EQ.0.) IFLAG=1
      HL(2)=-CLINE(1)/FAC
      IF(HL(2).EQ.0..AND.IFLAG.EQ.1) GO TO 21
      FAC=VZZ*ANOR
      W(1)=(XDZZ(2)*ANX(3)-XDZZ(3)*ANX(2))/FAC
      W(2)=(XDZZ(3)*ANX(1)-XDZZ(1)*ANX(3))/FAC
      W(3)=(XDZZ(1)*ANX(2)-XDZZ(2)*ANX(1))/FAC
      ZZ=HL(3)-W(3)
      Z=(HL(1)-W(1))**2
      Z=(HL(2)-W(2))**2+Z
      Z=ZZ**2+Z
      Z=SQRT(Z)/2.
      ROLL = 2.*ASIN(Z)
      IF(ZZ.LT.0.) ROLL=-ROLL
      IF(YAW.GT.3.1416) YAW=YAW-6.2832
C     THIS PRINTOUT IS FOR CHECKOUT.  IN NORMAL USE THERE WILL BE NO AZ,
C     EL, ROL, AND AL TO PRINT OUT.
   22 PRINT 103, AZ(I),YAW,EL(I),PITCH,ROL(I),ROLL,AL(I),ALPH,NITER
  103 FORMAT(15X,4(F5.2,4X,F5.2,6X),10X,I3)
   20 CONTINUE
      GO TO 50
```

```
   16 PRINT 104
  104 FORMAT(10X,*CL IS OUT OF BOUNDS.*)
      PRINT 102,TI(I),(XI(I,J),J=1,3),AZ(I),EL(I),ROL(I),AL(I)
      GO TO 50
   21 PRINT 105
  105 FORMAT(10X,*AIRCRAFT IS POINTED STRAIGHT UP.*)
      GO TO 52
   50 CONTINUE
 1000 CONTINUE
      END
```

```
      SUBROUTINE ALPHA(CL,ALPH,IFLAG,JFLAG)
C     THIS FUNCTION RETURNS THE ANGLE OF ATTACK FOR THE GIVEN CL.
C     ALPHA IS IN RADIANS.
C     IFLAG=1 FOR CL TOO LOW. JFLAG=1 FOR CL TOO HIGH.

      IFLAG=0
      JFLAG=0
      IF(CL.LT.-.2) GO TO 10
      IF(CL.LT..65) GO TO 11
      IF(CL.LT..75 ) GO TO 12
      IF (CL.LT..80) GO TO 13
      JFLAG=1
      RETURN
   10 IFLAG=1
      RETURN
   11 ALPH=0.326*CL-0.00436
      RETURN
   12 ALPH=0.639*CL-0.202
      RETURN
   13 ALPH=0.277+2.820*(CL-0.75)
      RETURN
      END
```

```
      FUNCTION QUE(H,S)
C     QUE IS DYNAMIC PRESSURE IN KG PER SQ METER.
C     H IS ALTITUDE ABOVE SL IN METERS. S IS SPEED IN METERS/SEC.

      SIG=EXP(-.0948*(H/1000.)**1.047)
      QUE=.0624*SIG*S*S
      RETURN
      END
```

```
      SUBROUTINE TRAJ(KPTS,XI,TI,XDI,XDDI,XD,XDD,B1,B2)
      DIMENSION XI(1000,3),XD(1000,3),XDD(1000,3),B1(1000,3),B2(1000,3)
      DIMENSION XDI(3),XDDI(3),ANEW(3),ADNEW(3),ADDNEW(3),TI(1000)
      DIMENSION Q1(3),Q2(3),AX(8,3),AT(8)

      DO 100 I=1,3
      XD(2,I)=XDI(I)
  100 XDD(2,I)=XDDI(I)
      M1=KPTS-7
      DO 300 JK=2,M1
      DO 200 J=1,8
      N=JK+J-1
      AT(J)=TI(N)
      DO 200 I=1,3
  200 AX(J,I)=XI(N,I)
      CALL FIT3(AX,AT,ANEW,ADNEW,ADDNEW,XDI,XDDI,Q1,Q2)
      M=JK+4
      DO 300 I=1,3
      XD(M,I)=ADNEW(I)
      XDD(M,I)=ADDNEW(I)
C     B1 ND B2 ARE AVAILABLE IF ONE WISHES TO INTERPOLATE TO OTHER TIMES
C     .  OTHERWISE THESE 6000 WORDS CAN BE ELIMINATED.
      B1(JK,I)=Q1(I)
  300 B2(JK,I)=Q2(I)
      RETURN
      END
```

```
      SUBROUTINE FIT3(AX,AT,ANEW,ADNEW,ADDNEW,XDI,XDDI,Q1,Q2)
      DIMENSION XDI(3),XDDI(3),ANEW(3),ADNEW(3),ADDNEW(3)
      DIMENSION Q1(3),Q2(3),AX(8,3),AT(8)
       DIMENSION TN(7),TN2(7),TN3(7),T(8),TAU(5),X(8)
C     USING SET OF 8 POINTS IN SEQUENCE. MAKES LEAST SQUARE FIT OF 3RD
C     DEGREE POLYNOMIAL THRU LAST THREE POINTS. KEEPING FIRST POINT. AND
C     ITS FIRST DERIVATIVE UNCHANGED.

      DO 1 J=1,8
    1 T(J)=AT(J)-AT(1)
      DO 2 K=1,5
    2 TAU(K)=0.
      DO 3 I=1,7
    3 TN(I)=T(I+1)
      DO 4 K=1,5
      DO 5 I=1,7
      TN(I)=TN(I)*T(I+1)
      IF(K.EQ.1)  TN2(I)=TN(I)
      IF(K.EQ.2)  TN3(I)=TN(I)
    5 TAU(K)=        TN(I)+TAU(K)
    4 CONTINUE
      DO 6 I=1,3
      XO=AX(1,I)
      VO=XDI(I)
```

```
      DO 7 J=2,8
    7 X(J)=AX(J,I)
      BETA=0
      ALPHA=X0*TAU(1)+V0*TAU(2)
      DO 8 J=1,7
    8 BETA=X(J+1)*TN2(J)+BETA
      B1=BETA-ALPHA
      BETA=0
      ALPHA=X0*TAU(2)+V0*TAU(3)
      DO 9 J=1,7
    9 BETA=X(J+1)*TN3(J)+BETA
      B2=BETA-ALPHA
C     SOLVE SET OF 2 EQUATIONS FOR TWO UNKNOWNS
      D=TAU(3)*TAU(5)-TAU(4)**2
      D1=TAU(5)*B1-TAU(4)*B2
      D2=TAU(3)*B2-TAU(4)*B1
      IF(D.EQ.0) GO TO 10
      A1=D1/D
      A2=D2/D
      Q1(I)=A1
      Q2(I)=A2
      ANEW(I)=X0+V0*T(5)+A1*TN2(4)+A2*TN3(4)
      ADNEW(I)=V0+2.*A1*T(5)+3.*A2*TN2(4)
      ADDNEW(I)=2.*A1+6.*A2*T(5)
      XDI(I)=V0+2.*A1*T(2)+3.*A2*TN2(1)
    6 CONTINUE
      RETURN
 10     CONTINUE
       PRINT 20,AT,TAU,D
       STOP 77
 20     FORMAT(5X,G15.8)
C     STOP 77 INDICATES THAT THE DETERMINANT OF THE SET OF EQUATIONS
C     IS 0 - I.E. NO SOLUTION
      RETURN
      END




      SUBROUTINE THEPHI(X,Y,Z,R,GR,THE,PHI)
C  THEPHI COMPUTES THE MAGNITUDE OF A VECTOR. THE MAGNITUDE OF ITS
C  PROJECTION ONTO THE X1,X2 PLANE AND THE AZIMUTH AND ELEVATION ANGLES.

      IF(X)5,10,15
    5 THE=ATAN(Y/X)+3.1415926536
      GO TO 20
   10 IF(Y)11,12,13
   11 THE=4.71238898
      GO TO 20
   12 THE=0.0
      PHI=1.5707963268
      GR=0.0
      R=ABS(Z)
      RETURN
```

```
13 THE=1.5707963268
   GO TO 20
15 THE=ATAN(Y/X)
   IF (Y.GE.0.0) GO TO 20
   THE=THE+6.2831853072
20 IF (Z.EQ.0.0) RETURN
   GR2=X*X+Y*Y
   R=SQRT(GR2+Z*Z)
   GR=SQRT(GR2)
   PHI=ATAN(Z/GR)
   RETURN
   END
```

```
    FUNCTION RANDEV(I)
    TYPE REAL I
    IF(I.NE.0.) GO TO 30
    IF(JX.NE.0) GO TO 20
    U1=RANF(0.) $ U2=RANF(0.)
    XX=SQRT(-2*ALOG(U1))
    P2=6.2831853*U2
    RANDEV=XX*COS(P2)
    XX=XX*SIN(P2)
    JX=1 $ RETURN
 20 RANDEV=XX
    JX=0 $ RETURN
 30 IF(I.GT.0.) GO TO 40
    RANDEV=RANF(-1.) $ RETURN
 40 Y=RANF(I) $ JX=0 $ RETURN
    END
```

DEFINITIONS OF PRINCIPAL VARIABLES IN PROGRAM *ANGLE*

ALNG	Component of acceleration along velocity vector due to aerodynamic and propulsion forces, meters/sec^2
ALPH	Current angle of attack, radians
ALPHP	Angle of attack at previous position; angle between velocity vector and longitudinal reference line of aircraft, radians
ALPHT	Thrust angle of attack; angle between velocity vector and thrust vector, radians
ALTB	Altitude of origin of reference coordinate system above sea level, meters
ANOR	Component of acceleration perpendicular to velocity vector due to aerodynamic and propulsion forces, meters/sec^2
ANX(J)	Value of Jth component of $\overrightarrow{ANOR}$; i.e., $\overrightarrow{ANOR} = (ANX(1),ANX(2),ANX(3))$
BETA	Yaw angle of aircraft; azimuthal direction of projection of longitudinal line onto a horizontal plane, positive counterclockwise from X axis, radians
CL	Lift coefficient, dimensionless
CLINE(J)	Value of Jth component of a vector along longitudinal reference line of aircraft
DP	Drag, either current or at previous position, kilograms
HL(J)	Value of Jth component of a horizontal unit vector perpendicular to aircraft longitudinal reference line
KPTS	Number of aircraft positions given
L	Lift (perpendicular to velocity vector), kilograms
QUE	Dynamic pressure, kilograms per square meter
ROLL	Roll angle; angle between aircraft plane of symmetry and a vertical plane containing the longitudinal reference line, positive for roll to the right, radians
S	Reference area of aircraft, square meters
T	Thrust, kilograms
TA	Thrust angle; angle of thrust vector above longitudinal reference line of aircraft, radians
TI(I)	Time when aircraft is at position I, sec
W(J)	Value of Jth component of a unit vector perpendicular to both velocity and $\overrightarrow{ANOR}$
WT	Weight of aircraft, kilograms
XD(I,J)	Value of Jth component of aircraft velocity at position I, meters/sec
XDD(I,J)	Value of Jth component of aircraft acceleration at position I, meters/sec^2
XDI(I)	Initial value of Ith coordinate of aircraft velocity
XDDI(I)	Initial value of Ith coordinate of aircraft acceleration
XI(I,J)	Value of Jth coordinate of aircraft position I, meters
ZETA	Pitch angle; angle between a horizontal plane and longitudinal reference line, positive for positive values of *CLINE(3), radians*