Test Procedures for Instantaneous Impact Point Prediction

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Scope

This document provides a generic test case for the verification and comparison of different IIP prediction algorithms utilized for range safety purposes during sounding rocket missions. Following a general description of the test case, the comprised data files are listed and a detailed description of the format is given for each file.

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1 Test Case 01 – Drag-Free IIP Prediction

1.1 Test Description

1.1.1 Scope

The present test case covers the prediction of instantaneous impact points (IIP) using a purely gravitational force model from given position and velocity measurements.

1.1.2 Test Data

State vectors in the Earth centered Earth fixed WGS84 reference system are provided for selected epochs of the Maxus-4 flight trajectory (Table 1.1). They cover the boost phase (up to t=65s since lift off) and the subsequent free flight phase up to the atmospheric reentry. Apogee is reached at t=454s at an altitude of 703km.

Table 1.1 Maxus-4 position and velocity vectors in the WGS84 system for selected epochs since lift-off

t [s]	x [m]	y [m]	z [m]	vx [m/s]	vy [m/s]	vz [m/s]
19.95	2247139.30	867101.95	5891775.01	115.22	14.78	526.40
39.95	2251294.83	867777.39	5910681.46	365.83	84.56	1442.58
59.95	2264504.74	871754.80	5952746.64	1016.41	340.55	2939.28
79.95	2285594.87	878896.31	6013290.17	1026.99	345.33	2951.82
99.95	2305498.90	885526.39	6070621.32	963.13	317.82	2780.63
199.95	2386297.08	910645.66	6306954.01	656.40	187.13	1955.94
299.95	2437367.43	923354.59	6463431.48	367.15	68.96	1179.65
399.95	2460034.42	924726.47	6543771.63	87.18	-40.11	430.00
499.95	2454881.61	915533.70	6549719.32	-190.26	-142.76	-311.04
599.95	2421847.05	896296.71	6481284.37	-471.44	-241.41	-1060.45
699.95	2360231.72	867299.88	6336751.16	-762.99	-338.41	-1836.21
799.95	2268624.46	828576.28	6112445.32	-1072.64	-436.49	-2659.98

The data are derived from GPS measurements obtained with an Ashtech G12 receiver onboard the Maxus-4 rocket and have been been corrected for a known timing error of the employed GPS receiver. As a result, all time tags are slightly offset from the integer second.

The geodetic coordinates of the Kiruna launch site are summarized in Table 1.2.

Table 1.2 Launch site coordinates

x [km]	y [km]	z [km]	λ [°]	φ [°]	h [km]
2245.768	866.743	5886.626	21.10384	67.89335	0.36259

Using a 10x10 Earth gravity field model and a numerical integration of the respective equations of motion, reference values for the instantaneous impact point are obtained by intersection of the predicted trajectories with the WGS84 Earth ellipsoid. The resulting IIP coordinates are collated in Table 1.3. Aside from the Cartesian IIP position, the geodetic longitude and latitude as well as the East and North component in the local horizontal coordinate system of the launch site are given.

Table 1.3 Predicted impact points for Maxus-4 in the WGS84 coordinate system and the local horizontal system of the launch site considering a purely gravitational trajectory model.

t [s]	x [km]	y [km]	z [km]	lon [deg]	lat [deg]	E [km]	N [km]
19.95	2236.934	859.717	5890.990	21.02319	67.99752	-3.373	11.621
39.95	2194.059	827.928	5911.494	20.67400	68.49351	-17.593	67.001
59.95	2190.084	799.309	5916.868	20.05042	68.62532	-42.861	82.007
79.95	2190.464	797.418	5916.982	20.00356	68.62812	-44.762	82.352
99.95	2190.303	797.526	5917.026	20.00743	68.62922	-44.603	82.472
199.95	2190.325	797.499	5917.022	20.00660	68.62911	-44.637	82.460
299.95	2190.334	797.487	5917.020	20.00624	68.62907	-44.651	82.456
399.95	2190.341	797.474	5917.019	20.00588	68.62905	-44.666	82.454
499.95	2190.343	797.465	5917.020	20.00567	68.62905	-44.675	82.455
599.95	2190.347	797.453	5917.020	20.00535	68.62907	-44.688	82.456
699.95	2190.342	797.447	5917.023	20.00526	68.62913	-44.691	82.463
799.95	2190.344	797.445	5917.022	20.00520	68.62912	-44.694	82.462

1.1.3 Acceptance Criteria

One of the following acceptance criteria shall be met for a successful test performance:

1. the Cartesian position of the computed instantaneous impact points shall match the reference values within 2 km in each axis *or*
2. the geodetic coordinates of the computed instantaneous impact points shall match the reference values within 0.05° in longitude and 0.02° in latitude *or*
3. the computed instantaneous impact point coordinates in the local horizontal system of the launch site shall match the reference values within 2 km in each axis.

1.2 Data Files

Input data and reference values for an extended set of test epochs are provided in three test data files:

Table 1.4 Data files for drag-free IIP prediction test

File name	Description
GTN_TST_0010_01_XYZ.dat	Maxus-4 position and velocity (Cartesian WGS84 coordinates)
GTN_TST_0010_01_POS.dat	Maxus-4 position and velocity in Ashtech $PASHR,POS GPS data format
GTN_TST_0010_01_IIP.dat	Reference values of instantaneous impact point for the above trajectory data

All files cover a time frame from 10s prior to lift off up to 850s into the flight (can removal) and provide records at 1s sampling intervals (except for a short outage near the boost end).

1.2.1 Cartesian State Vectors

The primary test data file GTN_TST_0010_01_XYZ.dat provides a consecutive listing of position and velocity coordinates for the Maxus-4 trajectory. The data are consistently expressed in a Cartesian Earth-fixed WGS84 system. The time tag refers to the time elapsed since lift-off. A truncated sample listing is given below. Note that the header and ruler have only be added to facilitate the reading and are not part of the actual data set.

```
     t[s]       x[m]         y[m]         z[m]      vx[m/s]   vy[m/s]   vz[m/s]
----+----1----+----2----+----3----+----4----+----5----+----6----+----7---

    -10.05  2245895.69   866791.86  5886962.59     0.01     -0.00      0.03
     -9.05  2245895.70   866791.87  5886962.63     0.00      0.00      0.02
…
     -0.05  2245895.71   866791.81  5886962.69     0.05      0.02      0.15
      0.95  2245898.23   866793.16  5886961.10     7.10      2.90     18.87
      1.95  2245909.29   866797.68  5886990.49    14.97      6.12     39.91
      2.95  2245963.25   866818.94  5887133.62    22.71      9.28     61.10
      3.95  2245954.66   866816.22  5887112.92    30.35     12.35     82.85
      4.95  2245988.70   866829.98  5887207.00    37.67     15.14    105.35
      5.95  2246029.76   866846.33  5887323.95    44.26     17.45    128.57
      6.95  2246076.91   866864.57  5887464.63    49.93     18.99    152.66
      7.95  2246129.30   866884.02  5887629.90    54.75     19.79    177.69
      8.95  2246186.25   866903.93  5887820.85    59.15     19.98    203.56
      9.95  2246247.72   866923.87  5888038.29    63.72     19.89    230.13
     10.95  2246313.99   866943.73  5888283.46    68.62     19.78    257.32
…
    845.95  2215823.25   807437.35  5980911.94 -1222.27  -482.12 -3057.66
    846.95  2214599.90   806955.14  5977851.65 -1223.98  -482.11 -3063.13
    847.95  2213376.70   806471.98  5974790.02 -1225.14  -482.60 -3066.84
    848.95  2212150.52   805989.65  5971721.86 -1226.35  -482.55 -3068.30
    849.95  2210919.88   805506.93  5968651.15 -1228.19  -481.70 -3066.89
```

1.2.2 Ashtech Position Messages

To facilitate testing of operational IIP prediction systems, the GTN_TST_0010_01_POS.dat data file provides the Maxus-4 trajectory data in the Ashtech proprietary $PASHR,POS message format. This format is compliant with the official NMEA standard protocol and is specified in Table 1.5. Position fixes are provided in geodetic Earth-fixed WGS-84 coordinates, whereas the velocity measurements are first expressed as heading, speed over ground and height above/below WGS84 Earth ellipsoid. Otherwise the data are fully consistent with the Cartesian state vector ephemeris provided in the GTN_TST_0010_01_XYZ.dat file. The launch time has (fictitiously) been assumed as 12:00:00 UTC.

A truncated sample listing of the POS message file is given below. Note that the ruler has only be added to facilitate the reading and is not part of the actual data file.

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8----+----9----+----0----+----1----+

$PASHR,POS,0,11,115949.95,6753.60091,N,02106.23027,E,+00362.59,,306.32,000.01,+000.03,01.9,00.0,00.0,00.0,MAX4*51
$PASHR,POS,0,11,115950.95,6753.60091,N,02106.23028,E,+00362.63,,000.00,000.01,+000.02,01.9,00.0,00.0,00.0,MAX4*5°
…
$PASHR,POS,0,11,115959.95,6753.60093,N,02106.23019,E,+00362.68,,005.71,000.01,+000.16,01.9,00.0,00.0,00.0,MAX4*5E
$PASHR,POS,0,11,120000.95,6753.59919,N,02106.23069,E,+00362.28,,091.10,000.29,+020.37,01.9,00.0,00.0,00.0,MAX4*5E
$PASHR,POS,0,11,120001.95,6753.59919,N,02106.23103,E,+00394.00,,083.11,000.63,+043.06,01.9,00.0,00.0,00.0,MAX4*5A
$PASHR,POS,0,11,120002.95,6753.59926,N,02106.23161,E,+00548.43,,060.77,001.07,+065.84,01.9,00.0,00.0,00.0,MAX4*51
$PASHR,POS,0,11,120003.95,6753.59955,N,02106.23240,E,+00525.87,,035.70,001.98,+089.09,01.9,00.0,00.0,00.0,MAX4*51
$PASHR,POS,0,11,120004.95,6753.60030,N,02106.23323,E,+00626.85,,015.41,004.11,+112.88,01.9,00.0,00.0,00.0,MAX4*5E
$PASHR,POS,0,11,120005.95,6753.60195,N,02106.23390,E,+00751.83,,004.56,008.40,+137.02,01.9,00.0,00.0,00.0,MAX4*55
$PASHR,POS,0,11,120006.95,6753.60523,N,02106.23396,E,+00901.20,,358.12,015.48,+161.54,01.9,00.0,00.0,00.0,MAX4*55
$PASHR,POS,0,11,120007.95,6753.61084,N,02106.23293,E,+01075.35,,354.48,025.28,+186.53,01.9,00.0,00.0,00.0,MAX4*5E
$PASHR,POS,0,11,120008.95,6753.61944,N,02106.23017,E,+01274.95,,351.96,036.93,+212.07,01.9,00.0,00.0,00.0,MAX4*58
$PASHR,POS,0,11,120009.95,6753.63130,N,02106.22514,E,+01500.69,,350.00,049.13,+238.28,01.9,00.0,00.0,00.0,MAX4*5B
$PASHR,POS,0,11,120010.95,6753.64655,N,02106.21752,E,+01753.79,,348.57,061.33,+265.18,01.9,00.0,00.0,00.0,MAX4*5E
…
$PASHR,POS,0,09,121405.95,6836.57757,N,02001.29258,E,+69467.59,,342.25,220.02,-3326.09,02.7,00.0,00.0,00.0,MAX4*64
$PASHR,POS,0,09,121406.95,6836.63497,N,02001.24266,E,+66138.68,,342.46,218.85,-3331.76,02.7,00.0,00.0,00.0,MAX4*62
$PASHR,POS,0,09,121407.95,6836.69226,N,02001.19131,E,+62808.45,,342.40,218.67,-3335.67,02.7,00.0,00.0,00.0,MAX4*65
$PASHR,POS,0,08,121408.95,6836.74959,N,02001.14254,E,+59471.22,,342.70,219.46,-3337.44,03.1,00.0,00.0,00.0,MAX4*67
$PASHR,POS,0,08,121409.95,6836.80863,N,02001.09540,E,+56130.05,,343.66,222.22,-3336.65,03.1,00.0,00.0,00.0,MAX4*6F
```

Table 1.5 Ashtech $PASHR,POS type message format for IIP test data. In accord with the NMEA protocol, all messages are complemented by a '$' header and a trailer comprising an asterisk ('*'), a two hex digit checksum and a <CR><LF> character terminator.

Quantity	Format	Units	# of Chars	Range
Sentence identifier	CCCCC		5	'PASHR'
single comma	C		1	','
Sentence content	CCC		3	'POS'
single comma	C		1	','
Raw/differential position	C	(see note 1)	1	'0' or '1'
single comma	C		1	','
Satellites used in Nav fix	XX		2	00 -> 12
single comma	C		1	','
UTC (time) of position	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
single comma	C		1	','
Latitude	ddmm.mmmmm	d = degree (int) m = minutes (float)	10	0000.00000 to 8959.99999
single comma	C		1	','
Latitude Direction	C		1	'N' or 'S'
single comma	C		1	','
Longitude	dddmm.mmmmm	d = degree (int) m = minutes (float)	11	0000.00000 to 8959.99999
single comma	C		1	','
Longitude Direction	C		1	'E' or 'W'
single comma	C		1	','
Altitude above/below WGS84 Earth ellipsoid	±FFFFF.FF	(see note 2)	9	
two commas	CC		2	',,'
Heading	FFF.FF	degrees	6	000.00 -> 359.99
single comma	C		1	','
Speed over ground	FFF.FF	knots	6	000.00 -> 999.99
single comma	C		1	','
Rate of climb	±FFF.FF	m/s	7	-999.99 -> 999.99
single comma	C		1	','
PDOP	FF.F		4	0 -> 99.9
single comma	C		1	','
Not used	FF.F		4	'00.0'
single comma	C		1	','
Not used	FF.F		4	'00.0'
single comma	C		1	','
Not used	FF.F		4	'00.0'
single comma	C		1	','
S/W Config Code	CCCC		4	'MAX4'

Nominal number of transmitted characters (including sentence header and trailer) = 109 + 6 = 115

Notes:

1) Raw/differential position 0 = Position is not differentially corrected
   1 = Position is differentially corrected with RTCM format
2) Data field is extended by one character for altitudes above 100km.
3) Data field is extended by one character for vertical velocities above 1000m/s.

1.2.3 Reference IIP Coordinates

Reference values of the instantaneous impact point coordinates for the test trajectory are provided in the GTN_TST_0010_01_IIP.dat file. For each one second sample, it provides the time since lift-off, the Cartesian IIP coordinates in the WGS84 system, the geodetic longitude and latitude (WGS84) and the East/North components of the IIP in the local launcher reference system. All data have been generated from a numerical integration of the equation of motion accounting for the Earth's gravity field in full accord with Sect. 1.1.2 and Table 1.3. The resulting IIP ground path is illustrated in Fig. 1.1.

t[s]	x[km]	y[km]	z[km]	lon[deg]	lat[deg]	E[km]	N[km]
-9.050	2245.768	866.743	5886.626	21.10384	67.89335	0.000	0.000
-8.050	2245.768	866.743	5886.626	21.10384	67.89335	0.000	0.000
...							
-0.050	2245.768	866.743	5886.626	21.10384	67.89335	0.000	0.000
0.950	2245.770	866.746	5886.625	21.10388	67.89332	0.002	-0.003
1.950	2245.769	866.748	5886.626	21.10396	67.89332	0.005	-0.003
2.950	2245.763	866.751	5886.627	21.10408	67.89337	0.010	0.002
3.950	2245.749	866.751	5886.633	21.10419	67.89349	0.015	0.016
4.950	2245.715	866.740	5886.647	21.10425	67.89384	0.017	0.055
5.950	2245.641	866.707	5886.680	21.10415	67.89462	0.013	0.142
6.950	2245.505	866.632	5886.743	21.10364	67.89611	-0.008	0.309
7.950	2245.289	866.501	5886.843	21.10258	67.89851	-0.053	0.576
8.950	2244.996	866.306	5886.983	21.10075	67.90185	-0.130	0.948
9.950	2244.640	866.049	5887.155	21.09809	67.90595	-0.241	1.405
10.950	2244.229	865.738	5887.357	21.09470	67.91074	-0.383	1.940
...							
845.950	2190.330	797.445	5917.027	20.00532	68.62924	-44.688	82.475
846.950	2190.334	797.455	5917.024	20.00550	68.62917	-44.681	82.468
847.950	2190.336	797.448	5917.024	20.00533	68.62917	-44.688	82.468
848.950	2190.323	797.447	5917.029	20.00542	68.62929	-44.684	82.481
849.950	2190.283	797.454	5917.043	20.00592	68.62964	-44.664	82.519

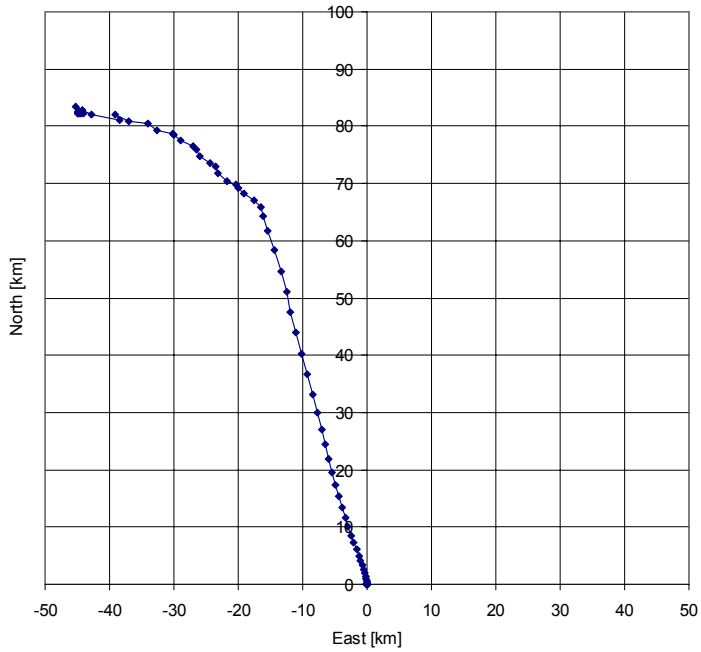

Fig. 1.1 Maxus-4 instantaneous impact point in the local horizontal coordinate system of the launch site.