Orbital Analysis of the Shenzhou-7 Manned Mission in Support of the Malindi Tracking Station

Technical Report

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ABSTRACT

This report presents an analysis of the orbital and ground coverage aspects of the third Chinese manned mission, Shenzhou-7, carried out in September 2008. The flight was supported by the Malindi tracking station, in Kenya, managed by the Italian Space Agency (ASI). Before and during the mission, the Space Flight Dynamics Laboratory of ISTI/CNR provided the ASI personnel in Malindi with trajectory and maneuver analysis, together with flight monitoring. Tracking passes and re-entry events predictions were independently derived and reconstructed with in-house research and simulations. In addition, also the most appropriate time windows for the first Chinese spacewalk, planned during this mission, were autonomously predicted and made available in advance to the ASI personnel in Malindi.

The Malindi ground station played an important role in the Shenzhou-7 flight, as it was in the case of the previous two manned missions. Due to its critical geographical position, in fact, Malindi neatly integrated the existing network of ground stations and tracking ships, covering also the beginning of the first Chinese extravehicular activity and a critical portion of the spacecraft re-entry, between the retro-rocket firing and the impact with the atmospheric interface.

1. THE SHENZHOU-7 MISSION

1.1 Introduction

After a three-year gap since the second manned flight, Shenzhou-6 [1], on 12 October 2005, China was ready, after a very careful planning, for a third still more ambitious mission, having implemented several improvements on the space vehicle and developed a space suit for Extravehicular Activity (EVA). The main goals of the third human tended flight were the launch of a three men crew on a nearly 3-day mission, the first Chinese EVA and the release of a small sub-satellite to conduct some undisclosed experiments.

Probably the launch was originally planned for the first half of October 2008, but was later moved to the last week of September. The change was reportedly attributed to the demand of longer periods of sunlight during the planned EVA, but this explanation was not convincing, because there were no significant changes in the duration of the illuminated portion of the orbit and the relevant geometry had to be, in any case, well known to mission planners quite early in the design process. A more plausible alternative could have been the desire to guarantee better daylight conditions in the primary capsule recovery site during landing and crew egress.

However, it cannot be excluded the possibility that propaganda and public relations considerations could have played a part in the decision, formalized after the NASA announcement to launch the last space shuttle servicing mission (STS-125) to the Hubble Space Telescope (HST) on 10 October 2008. It is, in fact, clear that flying Shenzhou-7 too close, together or after STS-125, a spectacular mission with multiple and very complex EVAs, would have significantly reduced the worldwide impact on the media of the first and relatively simple Chinese EVA, carried out more than 43 years after the first Soviet and American spacewalks. The opportunity to conclude the mission before the holidays following the National Day celebrations, on 1 October, might also have played a part in the decision.

Table 1.1

Time zones of interest during the Shenzhou-7 mission

Location	Time Zone
Beijing	**UTC + 8 hours**
Jiuquan Satellite Launch Center	**UTC + 8 hours**
Primary Landing Site	**UTC + 8 hours**
Malindi Ground Station	**UTC + 3 hours**
Italy	**UTC + 2 hours**

The flight of STS-125 was later delayed several months for new unexpected problems developed by HST near the originally intended launch date, but this is another story. At the

end of the review process, the launch of Shenzhou-7 was fixed at 13:10 UTC (21:10 Beijing time) on 25 September 2008 (see Table 1.1 for the time zones of interest in this report). The night launch time was probably chosen in order to guarantee the best combination of sunlight and ground coverage during the planned EVA and daylight conditions during the nominal reentry, after 45 revolutions and 68.5 hours of flight.

This was also the first time in which the second reentry opportunity for the nominal landing site was selected to conclude a Shenzhou mission [1]. The first opportunity, occurring after 14 orbits, had been chosen for the first manned mission, Shenzhou-5 (2003), and for the first unmanned spacecraft test, Shenzhou-1 (1999). The third opportunity, after 76 revolutions, had been chosen for the second manned flight, Shenzhou-6 (2005), while a fourth opportunity, after 107 revolutions, had been used for the unmanned re-entries of Shenzhou-2 (2001), Shenzhou-3 (2002) and Shenzhou-4 (2003).

1.2 Ground tracking and Malindi support

Based on the (incomplete) information available, for Shenzhou-7 the tracking network included at least five Yuanwang specially equipped ships, connected via satellite to the Chinese mainland, and eight ground stations, of which four in China and one each in Pakistan, Namibia, Chile and Kenya (see Table 1.2 and Figure 1.1). Possibly two other stations were active in China, one at the launch site and the other not far from Kashi, while the function of the Chile station, if any, was not clear. Also the role of a possible sixth tracking ship was not evident. At least two geostationary satellites provided communication links between the stations and the control center in Beijing, while the geostationary data relay satellite Tianlian-1, located at 77° E, probably supplied additional telemetry and voice contacts with the spacecraft (for ≈ 50 minutes per orbit; see Figure 1.2). However, all the TV broadcasts from space were transmitted only via UHF directly to the ships and ground stations overflown.

Table 1.2

Tracking stations used during the Shenzhou-7 mission

Station Name	Latitude (°)	Longitude (°E)
Chile	-31.75	287.95
Karachi	24.85	67.03
Kashi	39.48	76.03
Malindi-2	–3.00	40.19
Qingdao	36.07	120.37
Swakopmund	–22.67	14.57
Weinan	34.50	109.50
Xiamen	24.47	118.03
Yuanwang-1	29.00	130.00
Yuanwang-2	–30.00	200.00
Yuanwang-3	–25.00	9.00
Yuanwang-4	30.00	160.00
Yuanwang-5	0.00	205.00

As for the manned flights of Shenzhou-5, in October 2003, and Shenzhou-6, in October 2005, even in this case China asked for the availability and support of the Malindi S-band tracking station, in Kenya, managed by the Italian Space Agency (ASI). However, the new Malindi-2 facility was used this time, instead of the decommissioned Malindi-1, involved in the previous two missions. As in the past, having defined the appropriate instrumentation interfaces, a team of Chinese technicians was transferred in Malindi, to operate autonomously its own equipment, including the UHF gear, with voice and data links with the Beijing Aerospace Command and Control Center.

Fig. 1.1 – Geographical distribution of tracking ground stations and ships, launch complex (JSLC) and primary landing site

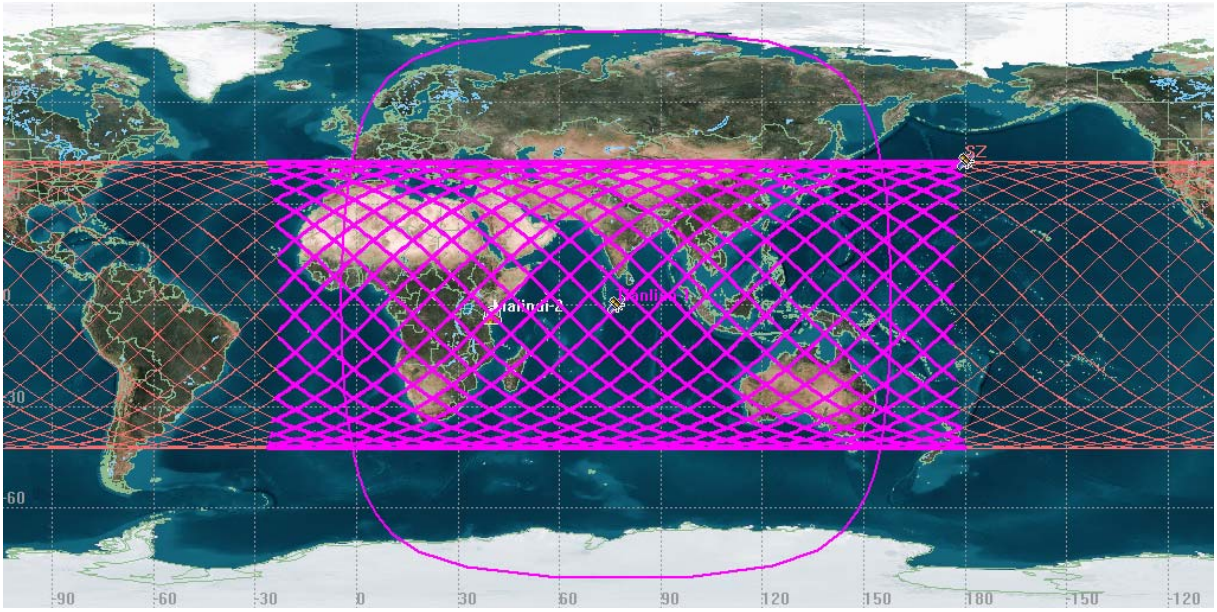

Fig. 1.2 – Tianlian-1 coverage of the Shenzhou orbits and the ground at 0° elevation (magenta lines)

During the Shenzhou-7 mission of 45 complete revolutions, 10 useful tracking passes over Malindi were planned, including the last one during the critical re-entry phase. The expected total acquisition time above 5° of elevation was about 60 minutes, with minimum pass duration of 299 s, maximum duration of 435 s and average duration of 359 s. The first useful pass over Malindi was foreseen about 7 hours and 49 minutes after the liftoff.

The importance of the Malindi station for the Shenzhou missions derives from its strategic position with respect to the spacecraft trajectory during the contingency and nominal reentries on the primary landing and recovery site (42° N, 112° E), near the town of Siziwang Qi, about 80 km north of Hohhot, the capital of Inner Mongolia. However, for the Shenzhou-7 flight, Malindi played an important role also during the first Chinese EVA, collecting the live images transmitted from the spacecraft during the best pass of the mission, on 27 September 2008. In particular, the Chinese UHF receiving equipment in Malindi was crucial in collecting the live TV broadcast showing the historical beginning of the spacewalk.

1.3 Pre-launch estimation of EVA windows

Based on official news releases, the Shenzhou-7 mission highlights would have been the first three men crew and the first spacewalk of the Chinese space program. However, no specific detail was revealed concerning the date, time and duration of the planned EVA, so a pre-launch analysis was carried out in order to identify the possible opportunity windows. The following constraints and hypotheses were adopted:

- Launch date and time: 25 September 2009, 13:10 UTC;
- Mission duration: 45 orbits and 68.5 hours;
- Same spacecraft trajectory as in the previous missions;
- EVA carried out completely in sunlight;
- Maximum and contiguous coverage from ground stations and tracking ships;
- Coverage from the Tianlian-1 geostationary data relay satellite.

By applying these criteria, the following EVA opportunity windows were found [2] [3] [4]:

- **EVA Window 1** (duration of 48 minutes): **26 September**, **08:04-08:52 UTC**. About 25 minutes of ground coverage above the elevation of 5°, including 5.2 minutes from Malindi. Tianlian-1 coverage at 0° elevation: 53.3 minutes, from 08:04 to 08:56 UTC. Spacecraft in sunlight for 54 minutes, from 07:58 to 08:52 UTC.
- **EVA Window 2** (duration of 44 minutes): **26 September**, **09:39-10:23 UTC**. About 35 minutes of ground coverage above the elevation of 5°, including 6.5 minutes from Malindi. Tianlian-1 coverage at 0° elevation: 54.5 minutes, from 09:39 to 10:33 UTC. Spacecraft in sunlight for 54 minutes, from 09:29 to 10:23 UTC.
- **EVA Window 3** (duration of 47 minutes): **27 September**, **08:23-09:10 UTC**. About 35 minutes of ground coverage above the elevation of 5°, including 7.3 minutes from Malindi. Tianlian-1 coverage at 0° elevation: 53.7 minutes, from 08:23 to 09:16 UTC. Spacecraft in sunlight for 53 minutes, from 08:17 to 09:10 UTC.

- **EVA Window 4** (duration of 42 minutes): **27 September**, **10:00-10:42 UTC**. About 25 minutes of ground coverage above the elevation of 5°, but no useful pass over Malindi. Tianlian-1 coverage at 0° elevation: 55 minutes, from 10:00 to 10:55 UTC. Spacecraft in sunlight for 54 minutes, from 09:48 to 10:42 UTC.

All these opportunities had the additional advantage of avoiding the crossing of the South Atlantic Anomaly (SAA), preventing the eventual exposure of the suited astronauts to additional radiation sources at the beginning of the egress operations [4].

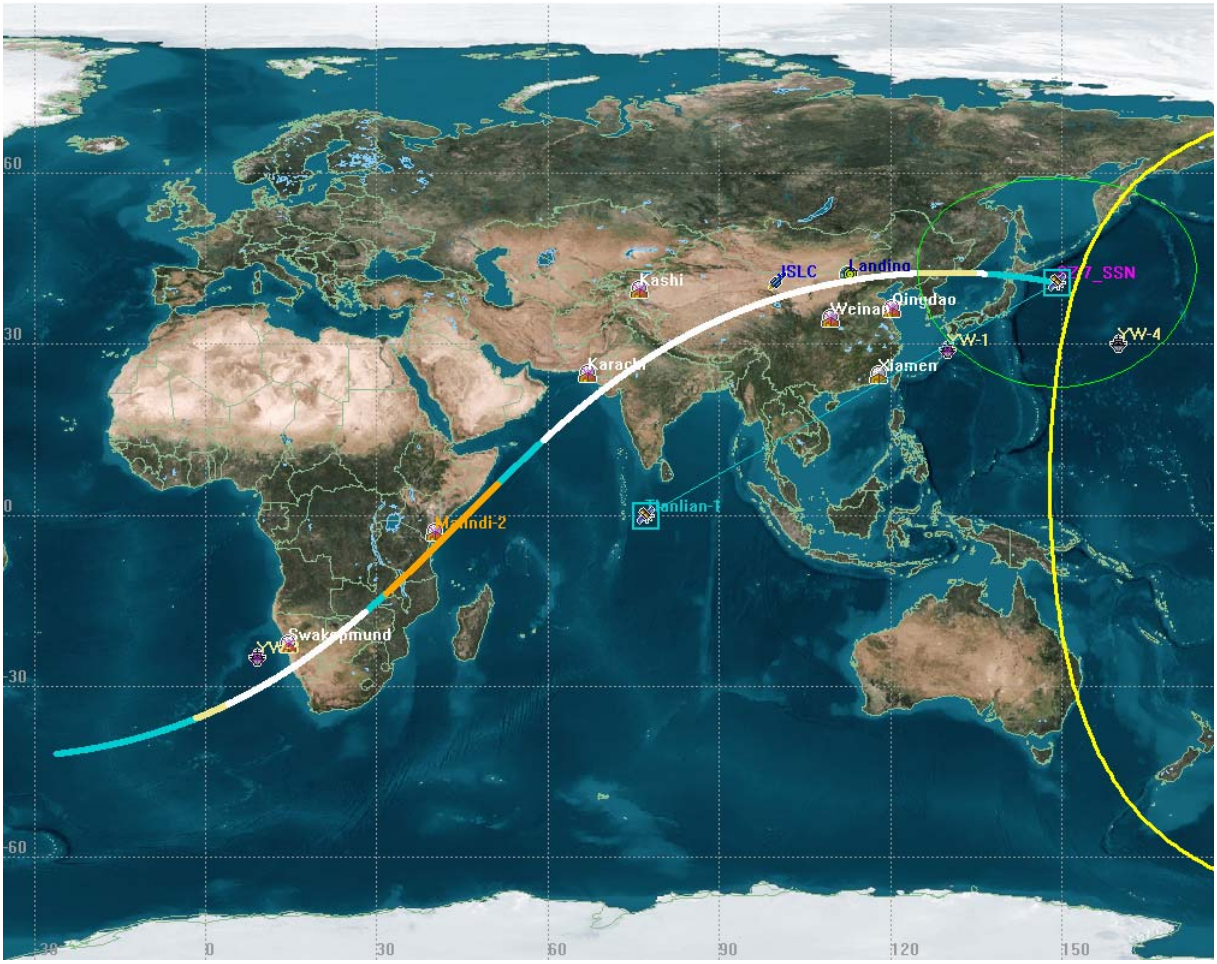

Fig. 1.3 – Satellite orbit portion corresponding to EVA Window 3: it was all in full sunlight (the sunlight/penumbra boundary is the yellow semi-circle on the right) and under Tianlian-1 coverage (cyano), while maximizing the contact time with ships (light yellow), ground stations (white) and Malindi (orange)

These results were clearly in disagreement with some claims appeared in the international media about an EVA attempt about 7-8 hours after the launch. On the contrary, they indicated the existence of two couples of opportunities on successive orbits, one on 26 September and the other one the day after. Moreover, taking into account all the available elements, Window

3, including the best pass over Malindi of the mission, appeared to be the most promising in terms of both ground coverage and illumination conditions (Figure 1.3), so it was indicated as the baseline EVA window to the Italian Malindi ground station [2].

1.4 Launch and orbit

Shenzhou-7 was launched with a Long March 2F (CZ-2F) rocket, from the Jiuquan Satellite Launch Center (JSLC), at 13:10:04.988 UTC on 25 September 2008. The ascent was nominal and the spacecraft was placed into a 200.1 × 346.8 km initial orbit, with an inclination of 42.40°. It acquired the COSPAR designator 2008-047A.

The spent CZ-2F upper stage (2008-047B) decayed from orbit on 17 October 2008, while four operational debris decayed on 29 September (2008-047C), 30 September (2008-047D and 2008-047E) and 1 October 2008 (2008-047F).

The Shenzhou-7 circularization maneuver occurred at 20:03 UTC, when two of the main motors of the service module were fired for about 64 seconds at the apogee. The new orbit, very close to the nominal one, had a minimum geodetic altitude of 333 km, a maximum geodetic altitude of 343 km, an inclination of 42.40° and an orbital period of 91.196 minutes.

As in the previous flights, the sub-satellite ground track of Shenzhou-7 repeated itself after 31 revolutions. The ground track pattern of the mission, spanning 45 revolutions, is shown in Figure 2.1. Two re-entry opportunities in the primary landing and recovery site existed. The first one occurred after 14 orbits, about 21.5 hours after the launch, while the second one, after 45 revolutions and about 68.5 hours after the launch, was selected in this case for the nominal end of the mission. Concerning the other properties of the nominal Shenzhou orbit, a detailed discussion can be found in [1].

1.5 First Chinese spacewalk

The first Chinese EVA, the main highlight of the mission, occurred during the 29th orbit, in agreement with the independent pre-launch estimation outlined in Section 1.3 [2], confirming that the assumptions made were sufficiently realistic. All the spacewalk occurred in sunlight, the coverage from ground stations and support ships was maximized, in order to broadcast, via line-of-sight UHF transmissions from the spacecraft, live TV images of the historical event, and the Tianlian-1 satellite was available for telemetry and voice relay. Moreover, the Malindi location played a pivotal role.

As predicted, the EVA occurred during Window 3, on 27 September 2008. The external hatch of the orbital module was opened around 08:38 UTC (Figure 1.4), as soon as Shenzhou-7 was in contact with Malindi, and was fully retracted a couple of minutes later, at 08:40 UTC (Figure 1.5). Around 08:42 UTC (Figure 1.6), at the minimum range (400 km) and maximum elevation (55°) from Malindi, the mission commander Zhai Zhigang, wearing a Chinese-developed Feitian space suit, slipped out of the orbital module in a head-first position, leaving completely the spacecraft around 08:44 UTC (Figure 1.7).

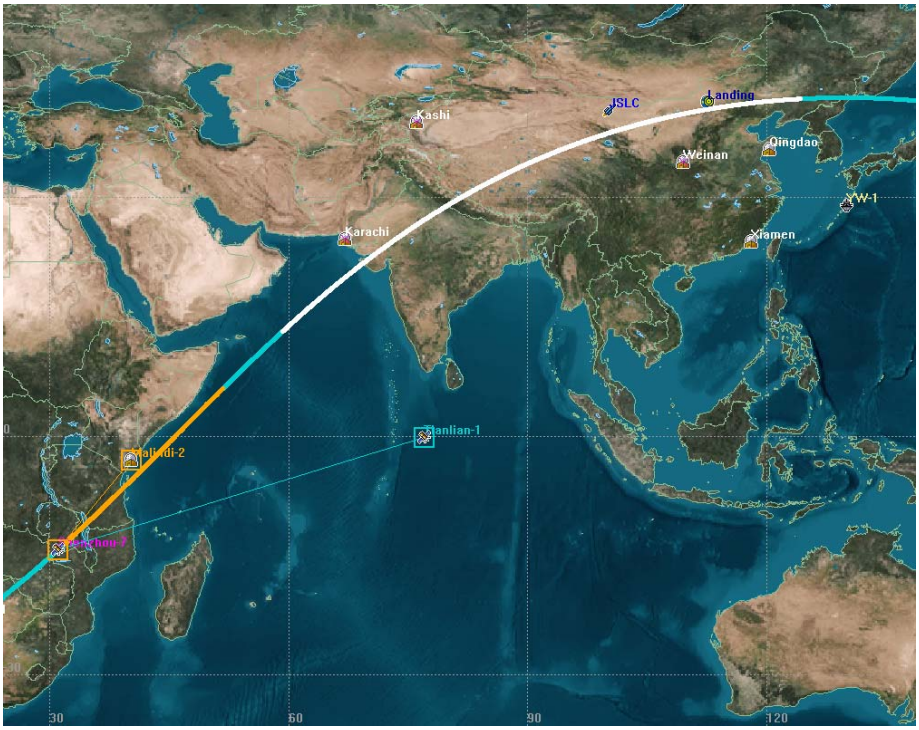

Fig. 1.4 – Position of Shenzhou-7 at the opening of the external hatch of the orbital module (08:38 UTC – 27 September 2008)

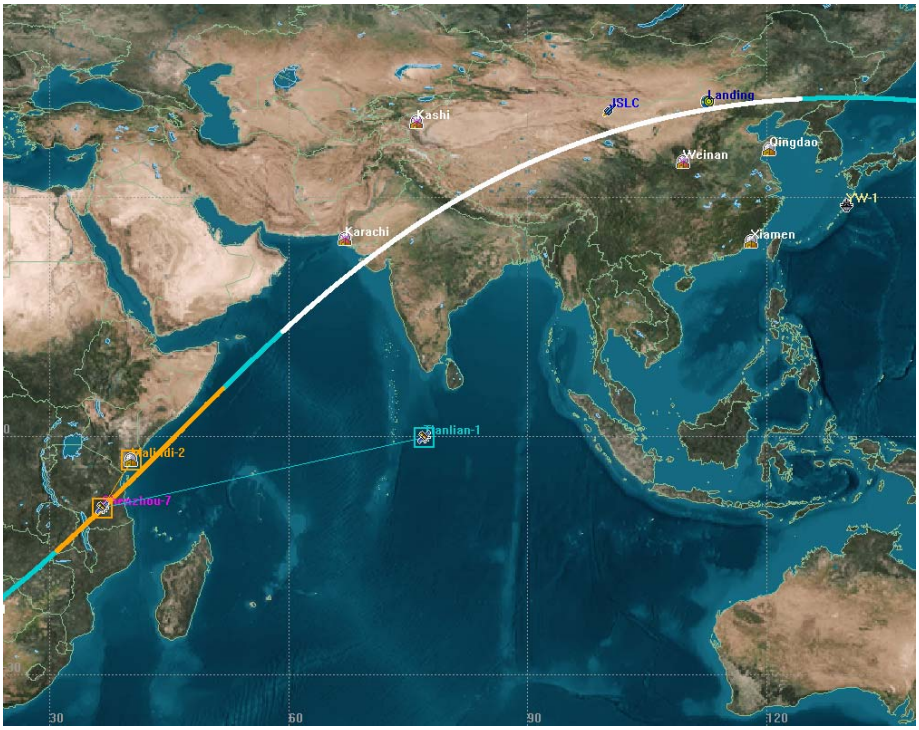

Fig. 1.5 – Position of Shenzhou-7 when the external hatch of the orbital module was fully retracted (08:40 UTC – 27 September 2008)

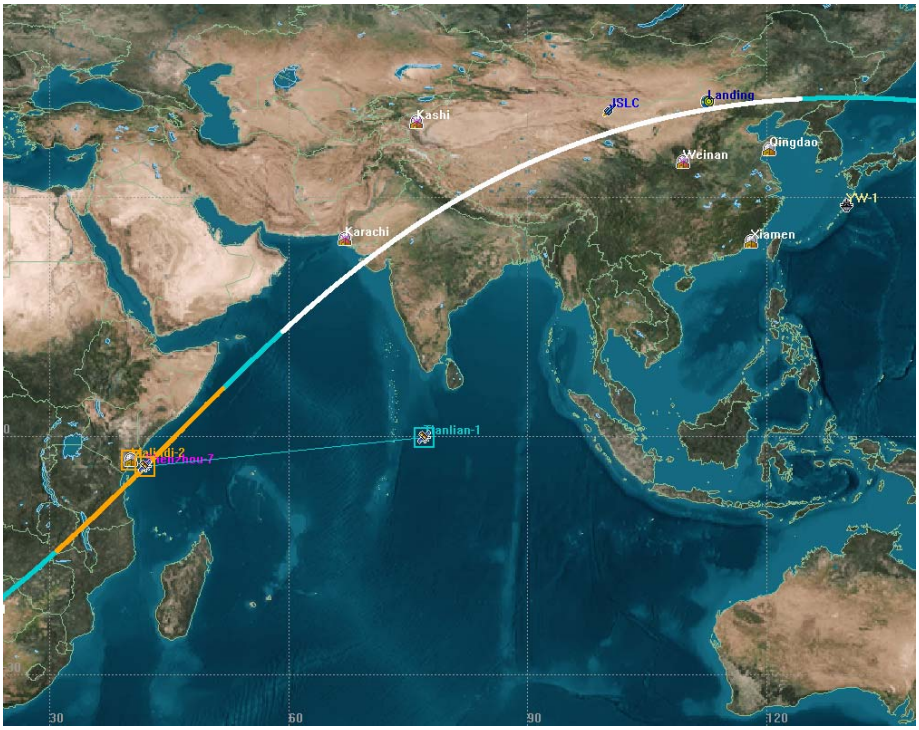

Fig. 1.6 – Position of Shenzhou-7 when Zhai Zhigang slipped out of the orbital module (08:42 UTC – 27 September 2008)

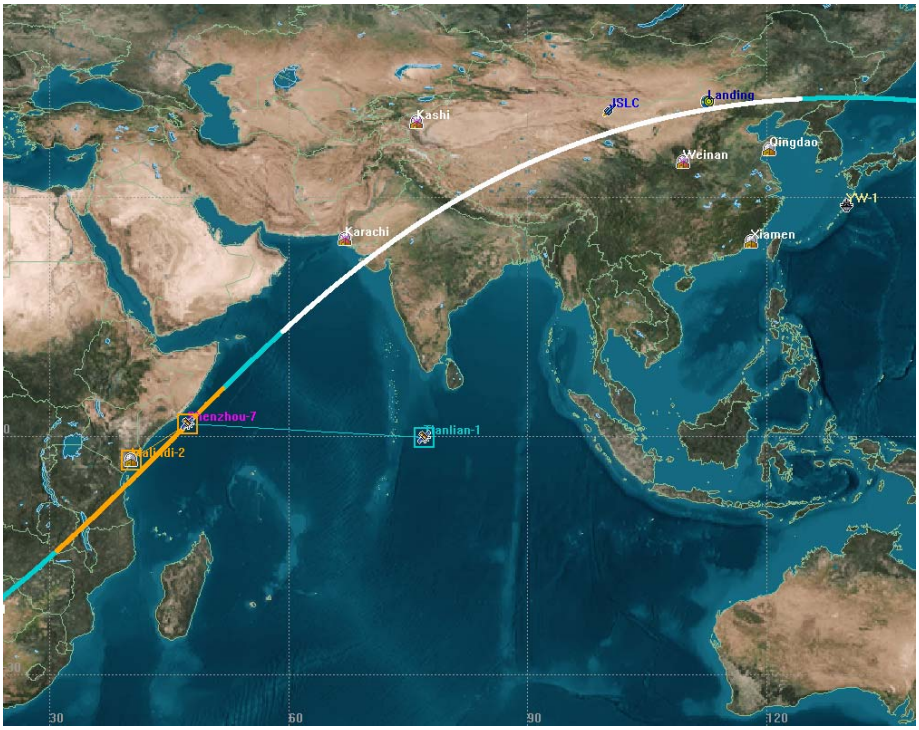

Fig. 1.7 – Position of Shenzhou-7 when Zhai Zhigang left completely the spacecraft (08:44 UTC – 27 September 2008)

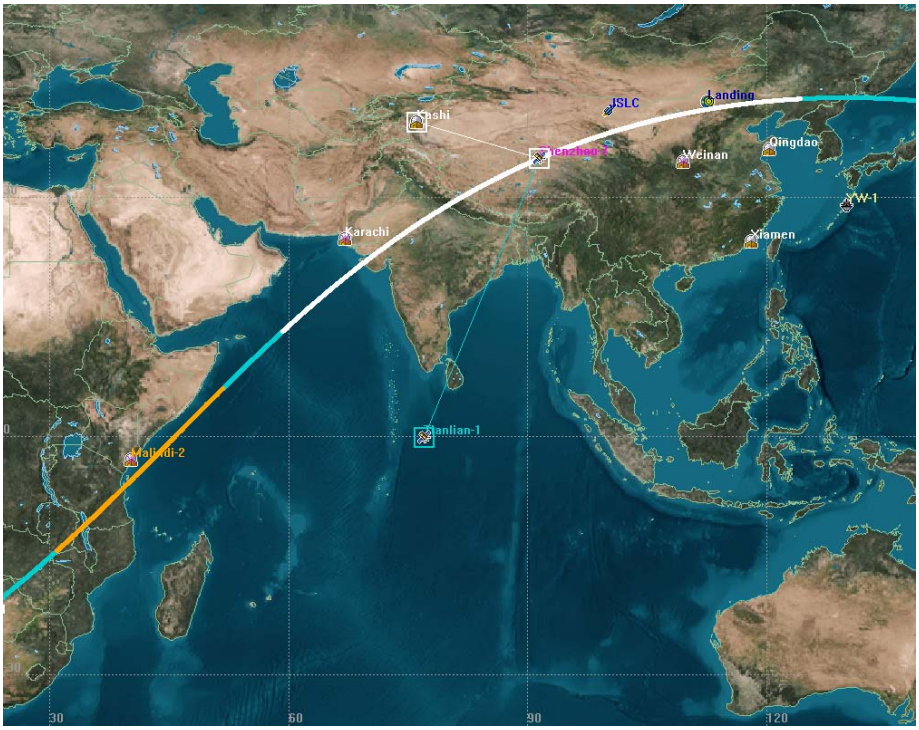

Fig. 1.8 – Position of Shenzhou-7 when Zhai Zhigang returned in the orbital module (08:58 UTC – 27 September 2008)

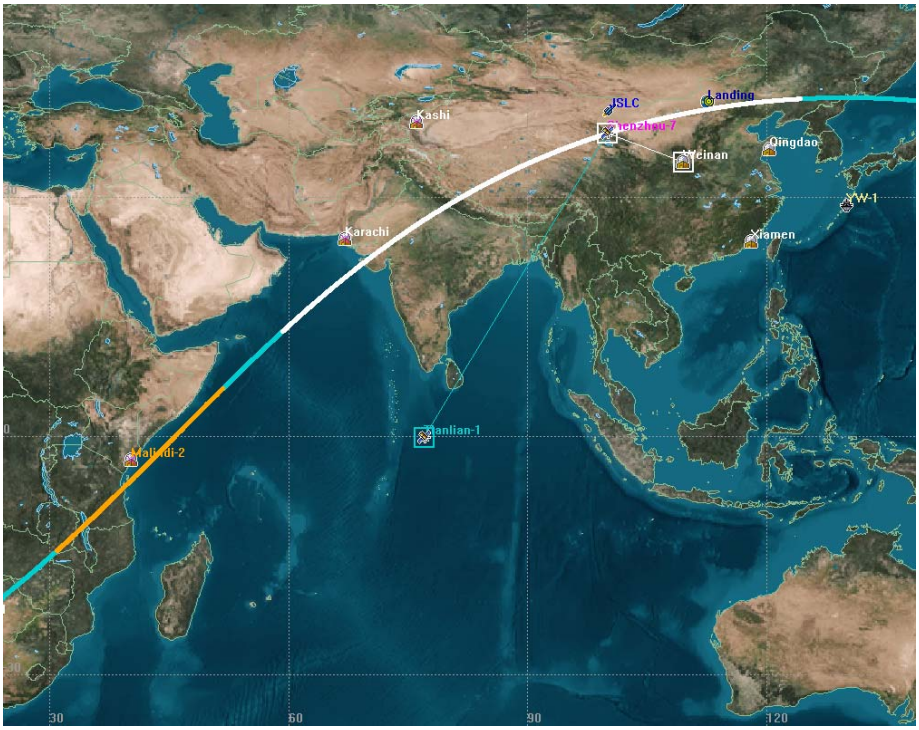

Fig. 1.9 – Position of Shenzhou-7 when the external hatch of the orbital module was closed (09:00 UTC – 27 September 2008)

About one minute later (08:45 UTC) the line-of-sight contact with Malindi was lost, as predicted, and only after approximately 3 minutes of blackout the TV broadcast was brought back through the Karachi ground station, in Pakistan, showing Liu Boming, wearing a Haiying space suit, handing Zhai Zhigang a Chinese flag from the hatch of the orbital module and later assisting him during the extravehicular activity. The third astronaut, Jing Haipeng, had instead remained in the re-entry module to monitor the EVA progress and the spacecraft status.

Having completed some simple experiments and operations on the exterior of the spacecraft, Zhai Zhigang returned in the orbital module around 08:58 UTC (Figure 1.8) and at 09:00 UTC (Figure 1.9) the hatch was closed, approximately 20 minutes after its opening. The final part of the EVA was monitored by the ground stations of Kashi and Weinan, in China.

1.6 BX-1 deployment

Approximately two hours and half after the successful completion of the EVA, a small sub-satellite mounted on top of the orbital module was deployed (2008-047G). Named Ban Xing (Chinese for *Companion Satellite*) or BX-1, it was a cube with a side of about 40 cm and a mass of 40 kg. It carried on board an ammonia gas propulsion system, communications equipment and two 150-megapixel stereo cameras.

Fig. 1.10 – Snapshot of Shenzhou-7 from BX-1, taken after the release of the mini-satellite (Xinhua News Agency)

Details on the mission of BX-1 were not disclosed, but after the release it sent back to the ground images of Shenzhou-7 (Figure 1.10), then drifted to more than 150 km away from the spacecraft. Following the return to earth of the re-entry module with the three astronauts, the mini-satellite, using its ammonia engines, performed approach and rendezvous tests aiming at the orbital module of Shenzhou-7, starting from a distance of more than 300 km. At the end BX-1 established a formation flying with the discarded module, circling the latter on a relative elliptical track of 4×8 km.

The mini-satellite completed its mission after more than 100 days since deployment and one year later BX-1 was still in orbit, at an altitude of 255×276 km.

1.7 Orbital module flight

The manned mission terminated as planned on 28 September 2008, resulting in the landing of the re-entry module and the atmospheric disintegration of the spacecraft service module. However, the orbital module, designated as 2008-047H, was left in orbit as in the previous Shenzhou flights, even though the lack of solar panels in this case (see Figure 1.10), in order to avoid any interference with the planned EVA, probably prevented the use of the module for additional experiments in the following months.

The analysis of the orbital elements has shown that no maneuver was carried out after separation from the rest of the spacecraft and the module was left to decay, due to air drag, being used for more than 100 days as the target for the BX-1 approach, rendezvous and formation flying tests. One year after the completion of the Shenzhou-7 mission, the orbital module was still in orbit, at an altitude of 278×293 km.

2. GROUND STATIONS COVERAGE

2.1 Ground network and Malindi coverage

Telemetry acquisition, tracking and communications (TT&C) for the Shenzhou-7 manned flight were assured by the ground stations and ships listed in Table 1.2. During the 68.5 hours mission, corresponding to 45 orbits, the ground coverage above the elevation of 5° is shown in Figure 2.1. Table 2.1 shows the total duration of the spacecraft passes, over each station or ship, in the same time span. The network was able to guarantee a quite complete coverage over China and each orbit presented at least one useful TT&C pass.

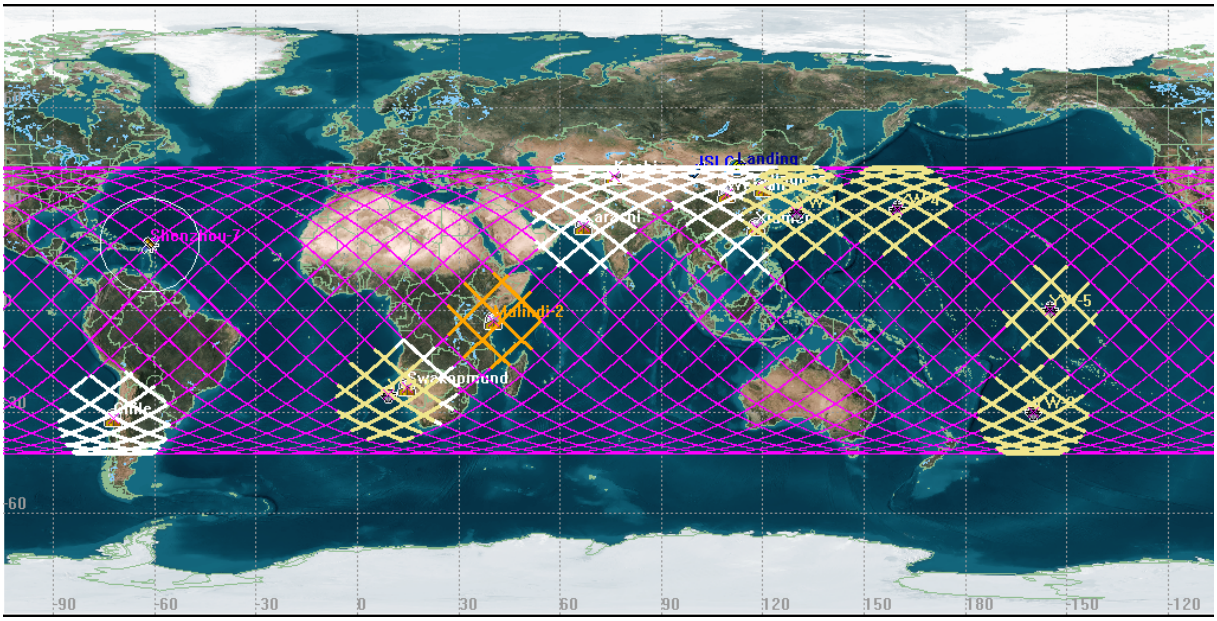

Fig. 2.1 – Ground coverage of the Shenzhou-7 flight (ground stations in white, Malindi in orange, tracking ships in light yellow)

Table 2.2 summarizes the useful passes over the Italian Malindi ground station, in Kenya, during the Shenzhou-7 mission. It is evident that one repetitive cycle of 31 orbits included 6 specific passes, three ascending (A) and three descending (D), whose geometry was nearly exactly reproduced after 31 revolutions, or about 47 hours [1], even though the second cycle was incomplete in this case, due to the short duration of the mission, i.e. just 45 revolutions. The pass pattern in each cycle of 31 revolutions was the following: D, D, A, A, D, A.

During the flight of Shenzhou-7 there were 10 useful passes over Malindi, the first 7 hours and 49 minutes after the launch, the last during the re-entry phase, after the retro-rockets burn and before the impact with the atmospheric interface (Table 2.2).

Table 2.1

Total duration of the Shenzhou-7 passes (elevation ≥ 5°)

Station Name	Passes Total Duration (min)
Chile	106
Karachi	81
Kashi	89
Malindi-2	60
Qingdao	102
Swakopmund	74
Weinan	106
Xiamen	75
Yuanwang-1	97
Yuanwang-2	105
Yuanwang-3	76
Yuanwang-4	91
Yuanwang-5	49

Table 2.2

Passes over the Italian Malindi-2 TT&C ground station (Kenya) during the Shenzhou-7 mission (elevation ≥ 5°)

Acquisition of Signal at 5° of Elevation (Mission Elapsed Time)	Type of Pass	Pass Duration (seconds)	Max Elevation (deg)	Min Range (km)
1st Pass Cycle				
0dd 07hh 48mm 51ss	Descending	303	11.1	1192
0dd 09hh 23mm 34ss	Descending	391	21.6	793
0dd 19hh 09mm 38ss	Ascending	311	11.7	1167
0dd 20hh 44mm 28ss	Ascending	388	21.0	808
1dd 08hh 07mm 12ss	Descending	435	56.3	396
1dd 19hh 28mm 06ss	Ascending	435	57.6	390
2nd Pass Cycle				
2dd 06hh 52mm 17ss	Descending	299	10.9	1202
2dd 08hh 26mm 57ss	Descending	393	22.0	784
2dd 18hh 13mm 01ss	Ascending	306	11.4	1177
2dd 19hh 48mm 09ss	Ascending	327	17.3	771
The EVA was initiated during the last pass of the 1st cycle				
The last pass occurred after the de-orbit burn				

3. DE-ORBITING, RE-ENTRY AND LANDING

3.1 Prediction of retro-rockets burn and de-orbiting trajectory

As usual, Chinese officials did not disclose in advance details concerning the timing of retro-rockets burn and the de-orbiting trajectory, so an analysis was carried out to deduce in advance such information in support of the Malindi ground station. By the way, it seems that also the Chinese personnel present in Malindi received, from the main control center, all critical information regarding an ensuing mission phase at the very last useful moment, lacking a full knowledge of the details before that time.

The prediction was based on the actual Shenzhou-7 orbit and on the de-orbiting burn and descent trajectory observed in the case of Shenzhou-6, in October 2005 [1]. Assuming a de-orbit burn duration of little less than 2.5 minutes, the following events were predicted [5] [6]:

- Retro-rockets firing: 28 September 2009, 08:50 UTC;
- Maneuver completion: 08:52:30 UTC;
- Descent module above the horizon of Malindi-2: 08:56:41 UTC;
- Maximum elevation from Malindi-2: 09:01:00 UTC;
- Descent module below the horizon of Malindi-2: 09:04:47 UTC;
- Descent module at atmospheric interface (altitude = 120 km): 09:13:46 UTC;
- Descent model over the Chinese airspace (altitude = 110 km): 09:14:30 UTC;
- Descent module landing in the primary recovery site: 09:37:50 UTC.

Based on the inferred de-orbit burn and trajectory, the details of the last predicted pass over Malindi-2 are presented in Table 3.1 [6]. The parameters of the predicted de-orbit trajectory are instead shown in Table 3.2.

Table 3.1

Predicted Shenzhou-7 re-entry pass over Malindi-2

UTC Time of 28 September 2008	Elevation (°)	Azimuth (°)	Range (km)	Altitude (km)
08:56:41	0.0	245.6	2030.5	315.7
08:57:41	3.6	251.1	1649.7	308.6
08:58:41	7.9	260.0	1291.4	300.6
08:59:41	13.0	275.3	985.8	292.0
09:00:41	17.4	301.7	798.5	282.6
09:01:00	17.8	312.0	779.8	279.5
09:01:41	16.0	334.6	817.6	272.7
09:02:41	10.2	358.6	1032.3	262.1
09:03:41	4.7	12.3	1352.4	251.0
09:04:47	0.0	21.0	1754.6	238.3

Table 3.2

**Predicted Shenzhou-7 de-orbit osculating trajectory
J2000 earth centered inertial osculating elements
Epoch: 28 September 2008, 09:01 UTC**

Trajectory Parameter	Predicted Value
Semi-major axis	6516.256 km
Eccentricity	0.0306
Inclination	42.4110°
Right ascension of the ascending node	176.5918°
Argument of perigee	138.4358°
True anomaly	223.6073°
Apogee radius vector	6715.7 km
Perigee radius vector	6316.9 km
Geodetic altitude	279.5 km

3.2 Retro-rockets burn, de-orbiting, re-entry and landing

As a matter of fact, the re-entry events occurred as predicted and the nominal de-orbit trajectory, shown in Table 3.3, was in good agreement with the predictions presented in Table 3.2. After the separation of the orbital module (2008-047H), the de-orbit burn was carried out while the manned spacecraft was simultaneously in contact with the Yuanwang-3 ship and the Swakopmund tracking station, in Namibia (Figures 3.1 and 3.2).

Table 3.3

**Shenzhou-7 nominal de-orbit trajectory
J2000 earth centered inertial osculating elements
Epoch: 28 September 2008, 09:01 UTC**

Trajectory Parameter	Nominal Value
Semi-major axis	6528.300 km
Eccentricity	0.028098
Inclination	42.424°
Right ascension of the ascending node	176.841°
Argument of perigee	134.474°
True anomaly	226.954°
Apogee radius vector	6711.7 km
Perigee radius vector	6344.9 km
Geodetic altitude	272.6 km

The details of the last nominal pass over Malindi-2 are presented in Table 3.4. Again, the agreement with the predictions shown in Table 3.1 was very good. The spacecraft rose over the horizon at 08:56:52 UTC, flying at a geodetic altitude of 309.4 km, reached the maximum elevation in the Malindi sky (about 17.3°) at 09:01:07 UTC, flying at an altitude of 271.4 km,

Fig. 3.1 – Shenzhou-7 at the de-orbiting burn start

Fig. 3.2 – Shenzhou-7 at the de-orbiting burn end

Table 3.4

Shenzhou-7 nominal re-entry pass over Malindi-2

UTC Time of 28 September 2008	Elevation (°)	Azimuth (°)	Range (km)	Altitude (km)
08:56:52	0.0	245.7	2009.5	309.4
08:57:52	3.5	251.4	1629.4	301.5
08:58:52	7.8	260.4	1270.8	293.0
08:59:52	13.0	276.3	966.9	283.7
09:00:52	17.1	303.4	786.8	273.9
09:01:07	17.3	311.9	772.9	271.4
09:01:52	15.3	336.4	818.9	263.5
09:02:52	9.5	359.9	1044.4	252.7
09:03:52	4.1	13.2	1370.9	241.3
09:04:49	0.0	20.7	1723.9	230.2

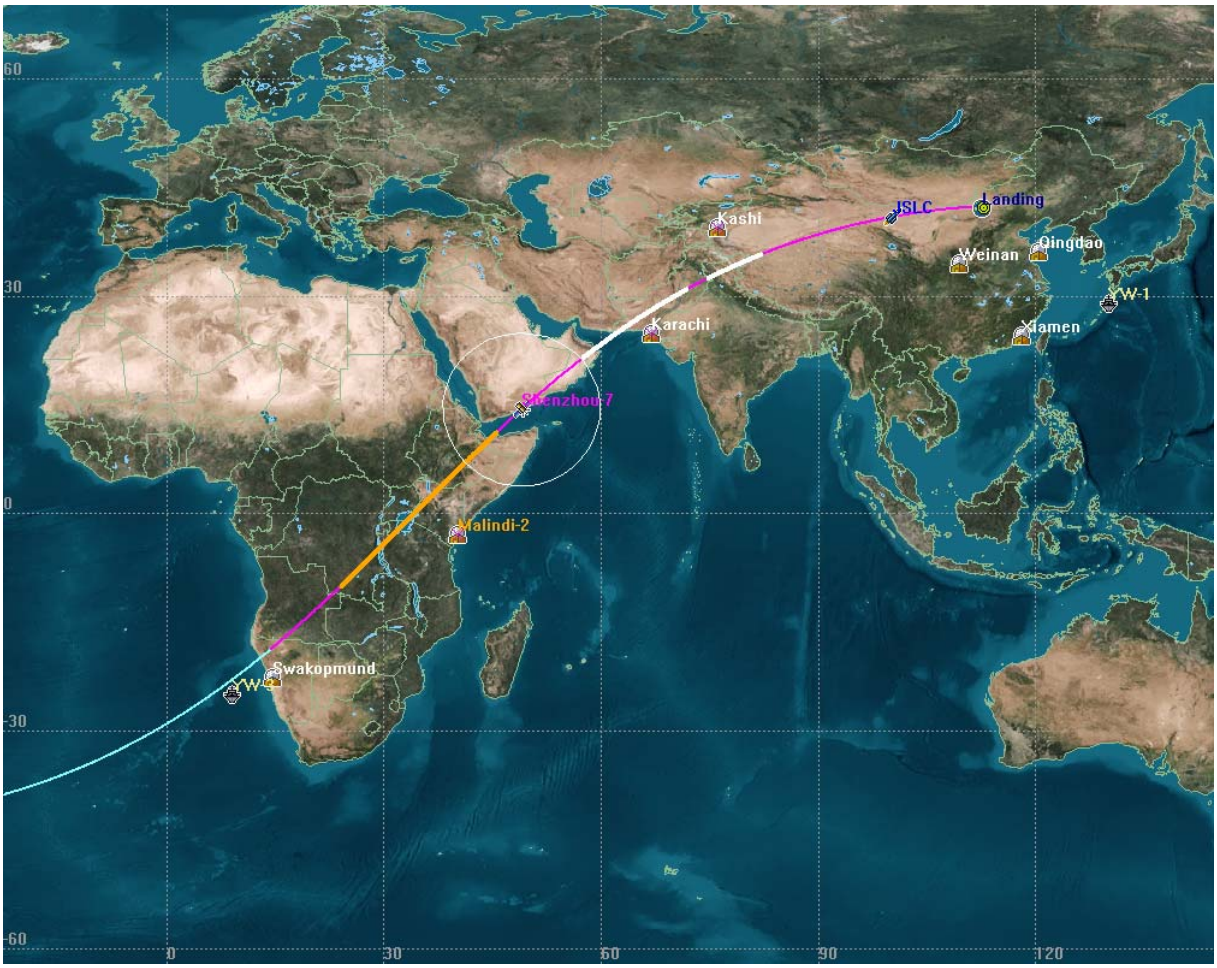

Fig. 3.3 – Re-entry ground track (magenta) of Shenzhou-7 with the Malindi-2, Karachi and Kashi visibility periods corresponding to elevations ≥ 5°

and disappeared under the horizon at 09:04:49 UTC, flying at an altitude of 230.2 km.

Over central Pakistan and in visibility of the Karachi tracking station, the service module, destined to burn up in the atmosphere, was separated from the re-entry capsule. The crossing of the atmospheric re-entry interface, at an altitude of 120 km, occurred at 09:13:27 UTC, close to the border between Pakistan and India (latitude: 32.259° N; longitude: 74.307° E), in visibility of the Kashi tracking station, in western China. Finally, the capsule crossed the Chinese air space at 09:14:52 UTC, at an altitude of about 102 km.

Having the velocity dropped below Mach 1, the main parachute deployed and three minutes later the heat shield at the bottom of the capsule was jettisoned, exposing the soft landing solid rockets and the gamma ray altimeter, designed to ignite them just before the impact with the ground. The soft-landing occurred at 09:37:45 UTC (17:37:45 local time), just 5 seconds before the time independently predicted (see Section 3.1).

The re-entry ground track (magenta) of Shenzhou-7 is shown in Figure 3.3, together with the visibility periods, corresponding to elevations equal or greater than 5°, from the Malindi-2 (orange), Karachi (white) and Kashi (white) tracking stations. From retro-rockets burnout to landing, the sub-satellite ground track spanned approximately 13,000 km.

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