[EN-A-059] Performance Analysis of Shenzhen Airlines' 4D/15 Tracking Demonstration

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Abstract: Following administrative instructions and guidance of CAAC, Shenzhen Airlines initiated a regional demonstration on 4D/15 tracking in its operation regions. Over 760 flights of 41 routes participated in the demonstration. Automatic downlink ACARS position reports were used to convey 4D position information to the AOC of Shenzhen Airlines in a periodical manner. The data analysis suggests that the Shenzhen Airlines has qualified 4D/15 tracking capability in its operating regions using ACARS as the tracking source for 4D position of its flights. Analysis of tracking gaps and corresponding mitigation measures will help the operator limit the related operation risk at an acceptable level.

Keywords: GADSS, Normal Flight Tracking, Performance Analysis

1. INTRODUCTION

The reason for the lost of Malaysia Airlines Flight MH370, whose echo disappeared on air traffic controllers' surveillance radar screen on March 8th 2014, has been remaining a mystery. Nevertheless, the wreckage or the flight data recorder has yet to be located after a three-year-long international cooperated search and rescue [1][2].

After this shocking event happened, ICAO, IATA, with other global organizations, raised several meetings and assigned various working groups aiming to find solutions to ensure that aircrafts, in all phases of flight, should be kept being tracked globally[3]. The ATTF, assigned by IATA had developed some high level operation requirements. This eventually evolves as the final proposal of concept of operations, which is known as the GADSS – Global Aeronautical Distress and Safety System. It was endorsed by ICAO on the Second High-level Safety Conference (HLSC 2015) and thus becomes the guidance for global flight tracking for the future [4]. The GADSS defines concept of operation for aircraft tracking throughout all phases of flight, by maintaining aircraft's up-to-date position records, and even retrieving the location of survivors and recoverable flight data in case of distress [5].

For implementing and enhancing the global flight tracking capability in the near term, ICAO appointed the Normal Aircraft Tracking Initiative Implementation Steering Committee (NATII SC) to find the best way for tracking a flight under normal condition using existing technologies and systems, and then propose policies, recommendations and guidance materials for normal flight tracking. After one-year work, the NATII had proposed their normal flight tracking Standards and Recommended Practices (SARPs) on normal flight tracking. This outcome becomes the 39th Amendment in Annex 6 – Operations of Aircraft, Part I – International Commercial Air Transport – Aeroplane. These SARPs had become effective in August of 2016 and will be applicable in November of 2018.

Taking the operation safety as the first priority of duty, Civil Aviation Administration of China endeavors to implement and enhance the global flight tracking capability of China's civil aviation. An Advisory Circular (AC), regarding the policies global flight tracking policies of China and normal flight tracking requirements for China operators, was drafted with the development of ICAO SARPs. The draft version of AC published in May of 2016 for public opinions consultant. Officially issued in August of 2016, this AC requires operators of China to establish their core flight tracking capability in their operation regions.

Following the administrative instructions and guidance of CAAC, Shenzhen Airlines started to enhance their flight tracking capability under normal conditions to fulfill the requirements in AC which would become applicable by the end of 2016. In order to evaluate the current capability of normal fight tracking and also reveal potential operation risks, Shenzhen Airlines initiated a regional demonstration tracking in its operation regions from August to September of 2016. The results of tracking data analysis suggest that the mean time interval of position reports received on ground during the demonstration is around 10 minutes.

This paper investigates the performance of Shenzhen Airlines regional demonstration on normal flight tracking. The rest contents are organized as follows: the normal flight tracking requirements mandated by ICAO and CAAC are introduced in the second part, followed by the regional demonstration plan of Shenzhen Airlines. Regional demonstration data analysis is carried on in succession. A summary is settled as the last part of the paper.

2. NORMAL FLIGHT TRACKING

2.1 The ICAO SARPs

The SARPs in 39th Amendment of Annex 6 Part I suggest that operators shall establish their aircraft tracking capability to track airplanes throughout their areas of operations. And operators are required to track the 4D position (latitude, longitude, height and time) of airplanes by automatic mechanisms at least every 15 minutes during the operation which is planned in an oceanic areas when: (1) the maximum certificated take-off mass of the airplane exceeds 45.5 tons and the seating capability is greater than 19, and (2) the Air Traffic Service could not maintain a tracking of the airplane’s 4D position at least every 15 minutes. This requirement that the operators shall take the responsibility to keep their flights tracked is known as 4D/15 tracking [6].

The means to achieve this goal can be diverse as long as the 4D position reports are sent automatically from the airplane airborne, which indicates that this is a performance based requirement and no technologies and/or service is specified. Typically, the Aircraft Communications Addressing and Reporting System (ACARS), Automatic Dependent Surveillance – Broadcast (ADS-B) and other systems capable of providing 4D poisons of aircraft can be employed by operators as solutions.

2.2 The CAAC Requirements

The Advisory Circular of normal flight tracking requirements for operators of China was issued in August 2016. This AC suggests that all the operators of China should establish their core flight tracking capability throughout their operation regions. Especially for those CCAR-121 operators, operations of international or regional passenger flights with the airplane of that maximum take-off mass over 27 tons shall in compliance with the 4D/15 tracking requirements outside the 9 (BEIJING, SHENYANG, LANZHOU, URUMQI, WUHAN, KUNMING, SHANGHAI, GUANGZHOU and SANYA) of 11 China FIRs by the end of 2016. This 4D/15 tracking requirement of CAAC is applicable to passenger transportations without a seat capacity threshold. Besides, the 4D/15 tracking is required for the operations outside the 9 of 11 China FIRs regardless of whether they are in an oceanic area. As for the operations within the above 9 FIRs of China, the air traffic service of China is committed to obtaining and maintaining the positions of flights [7].

As 97% of transportation fleets of China had already been ACARS capable at the end of 2015, using ACARS position reports is one of the feasible ways to achieve CAAC’s 4D/15 tracking provisions, which is of a higher standards than that of the ICAO SARPs.

3. REGIONAL DEMONSTRATION PLAN

As the AC issued in August 2016, it requires that operators of China to fulfill the requirements by December of 2016. Following administrative instructions and guidance of CAAC, a regional demonstration was initiated from August of 2016, in order to evaluate the current status and normal flight tracking capability of Shenzhen Airlines at that time. This demonstration can also estimate the performance of the ACARS position reports utilized for 4D/15 tracking.

The major aims for the demonstration are (1) evaluating current 4D/15 tracking capability of Shenzhen Airlines using ACARS position reports in all of its operation regions where CAAC mandates to achieve 4D/15 tracking requirements, (2) trying to find out whether there is any gap for ACARS coverage, and (3) the trial for the procedures and risk management mitigations established for 4D/15 tracking.

A demonstration plan was carefully designed in advance. The ACARS avionics are set to send ACARS position reports of time interval at 8 or 10 minutes regarding to the avionics model. The interval setting is the result of considering balance between system performance and financial cost: a longer interval will reduce cost of ACARS communications while leave a tight budget for lag of ACARS position reports’ transmission, which may cause a bluffing false alert to the ground AOC monitoring system when the communication network encounters fluctuated performance on quality of service. On the flip side, a high reporting frequency will dramatically amplify the communication cost, especially for the ACARS system since the communication provider charges by the flow-quantity usage.

A dedicated ground flight tracking system was developed for receiving and analyzing position reports from the flights, and it can raise alert to dispatchers and other personnel who is in charge of flight tracking when a desired position report of a flight is not received on time during its operation.

The demonstration started from August 30th to September 29th, 2016. Total 763 flights of 41 routes conducted by Shenzhen Airlines were involved in the demonstration. A complete list of the demonstrating routes is shown as in Table 1, the ICAO codes are used to present departure and arrival airports.

Besides international and regional flights, some domestic flights are also participated in the demonstration, such as Flight ZH9440, Sanya (ZJSY) – Yangzhou (ZSYA) – Harrbin (ZYHB), and Flight ZH9492, Sanya (ZHSY) – Wenzhou (ZSWZ) – Shenyang (ZYTX). The consideration for including these flights into the demonstration is to examine the operator's tracking capability during operations over the waters.

An illustrative map of the routes in demonstration is shown in Figure 1.

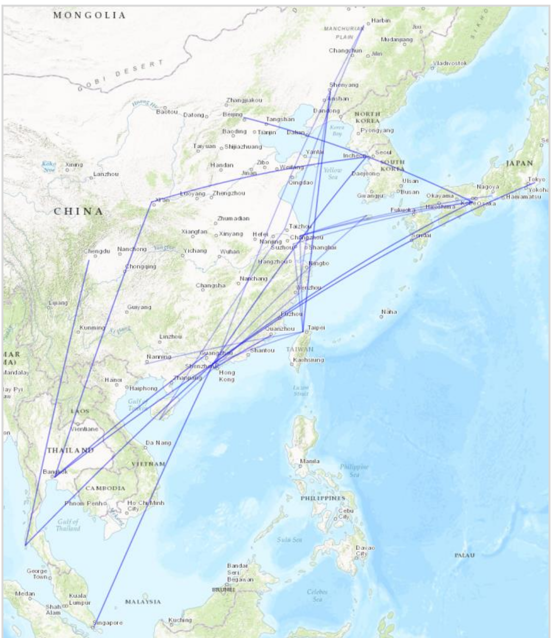

Figure 1 Routes in Demonstration

4. DATA ANALYSIS

A total of 13737 raw ACARS position reports and 3161 ACARS OOOI messages were received during the whole demonstration. After a preprocessing, duplicated and invalid position reports were washed out, 13374 effective reports are then analyzed. The time stamp of OFF messages is considered as the departure time of a flight, from which a 4D position is expected every 15 minutes until the ONN message triggered which indicates the flight finished.

Table 1 Routes of the Regional Demonstration

Flight Number	Departure Airport	Arrival Airport
ZH9003	ZGSZ	VTBS
ZH9004	VTBS	ZGSZ
ZH9013	ZLXY	VTBS
ZH9014	VTBS	ZLXY
ZH9015	ZBAA	RJBB
ZH9016	RJBB	ZBAA
ZH9017	ZLXY	RKSI
ZH9018	RKSI	ZLXY
ZH9022	RCTP	ZSWX
ZH9025	ZYTX	RCTP
ZH9026	RCTP	ZYTX
ZH9031	ZGGG	VTBS
ZH9032	VTBS	ZGGG
ZH9037	ZUUU	VTSP
ZH9038	VTSP	ZUUU
ZH9039	ZGSZ	RKPC
ZH9041	ZSQZ	VHHH
ZH9042	VHHH	ZSQZ
ZH9051	ZSNT	RCTP
ZH9053	ZSNT	RJBB
ZH9056	RJGG	ZSNT
ZH9058	RKPC	ZSNT
ZH9063	ZGSZ	RJBB
ZH9064	RJBB	ZGSZ
ZH9065	ZGSZ	RJAA
ZH9066	RJAA	ZGSZ
ZH9071	ZGSZ	VTSP
ZH9072	VTSP	ZGSZ
ZH9081	ZSWX	RJBB
ZH9095	ZGSZ	RCTP
ZH9440-1	ZJSY	ZSYA
ZH9440-2	ZSYA	ZYHB
ZH9463-1	ZYHB	ZSYT
ZH9463-2	ZSYT	VHHH
ZH9492-1	ZJSY	ZSWZ
ZH9492-2	ZSWZ	ZYTX
ZH9590	RCTP	ZGNN
ZH9787	ZGSZ	RKSI
ZH9788	RKSI	ZGSZ
ZH9791	ZGSZ	WSSS
ZH9792	WSSS	ZGSZ

The average flight time of each flight can be calculated by

$$\bar{t}_{opt} = \frac{\sum_{i=1}^{N} t_i}{N} \tag{1}$$

where t_i is the time duration of the ith flight of the route, calculated from take-off to landing by using the ACARS OFF and ONN messages, and N is the total number of flights.

The average position reports per operation of each flight is defined by

$$\overline{Cnt}_{pos} = \frac{\sum_{i=1}^{N} Cnt_{i\,pos.}}{N} \tag{2}$$

where the $Cnt_{i\,pos}$ is the number of ACARS position reports received during the ith flight, besides the OFF or ONN messages. N is the total count of flights as mentioned above.

The average position report interval is calculated by

$$\bar{t}_{pos.int.} = \frac{\sum_{i=1}^{N} \bar{t}_{i\,pos.int.}}{N} \tag{3}$$

where $\bar{t}_{pos.int.}$ is the average tracking interval of the ith flight given by

$$\bar{t}_{i\,pos.int.} = \frac{t_{i\,ONN} - t_{i\,OFF}}{Cnt_{i\,pos} + 1} \tag{4}$$

Equation (4) indicates that the total time from take-off $t_{i\,OFF}$ through its landing $t_{i\,ONN}$ of the ith flight divided by $Cnt_{i\,pos} + 1$ intervals yields the average tracking interval $\bar{t}_{i\,pos.int.}$ of this flight.

The expected number of position reports $\widehat{Cnt}_{pos.}$ required by 4D/15 tracking based on operation time of each flight can be obtained by

$$\widehat{Cnt}_{i\,pos.} = \frac{t_{i\,ONN} - t_{i\,OFF}}{15} \tag{5}$$

where i in subscripts denotes the ith flight of each route. By using this expected count of position reports, the average numbers and ratios of missed position reports for each route then can be obtained through,

$$\overline{\widehat{Cnt}}_{pos.} = \frac{\sum_{i=1}^{N} \widehat{Cnt}_{i\,pos.}}{N} \tag{6}$$

Since the time intervals set airborne for automatic position reports are 10 minutes, the average expected counts of position reports are lower than the received counts, as shown in Figure 2.

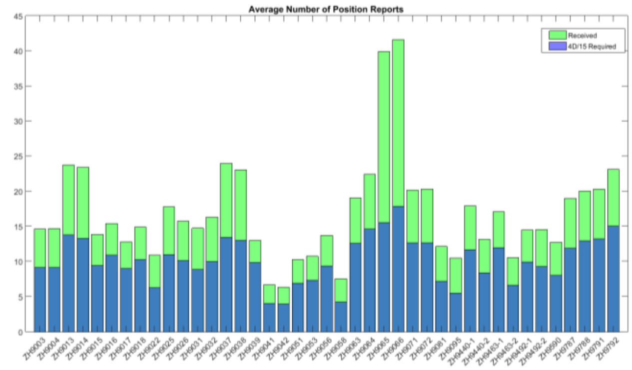

Figure 2 Average Number of Position Reports

As recommended by ICAO SARPs, an operator should establish core tracking capability in its operation region. And CAAC also requires that China operators shall track their flight outside the 9 of 11 of China FIRs in the 4D/15 manners. Those time intervals that are greater than 15 minutes then can be considered as gaps, in the tracking point of view, within the operation region. Understanding these tracking gaps' occurrence would help to establish and improve the airlines' tracking capability, which is one of the major objectives of this demonstration.

The total number of intervals that are greater than 15 minutes is 117 for the whole demonstration, based on statistics of 13374 valid ACARS position reports. The percentage frequency plot of these tracking gaps is shown in Figure 3.

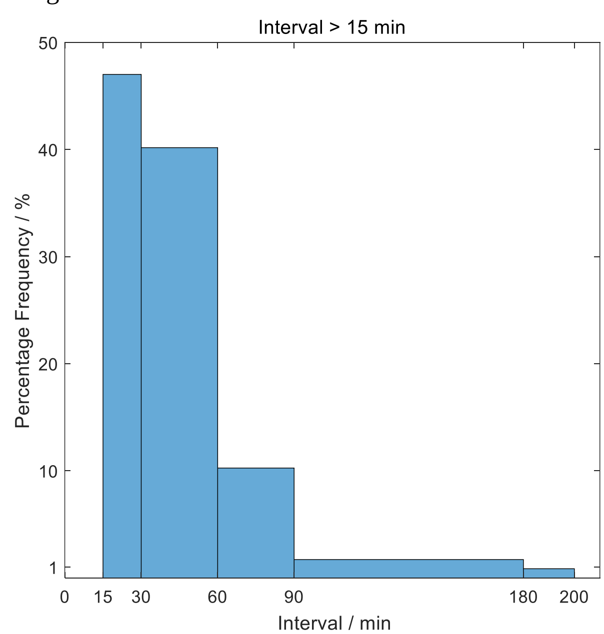

Figure 3 Percentage Frequency for Tracking Gaps

The time intervals that fall into 15 – 30 minutes are around 47% among all the tracking gaps occurred. About 40% is in the range of 30 – 60 minutes while 10% is between 60 – 90 minutes. The percentage of intervals that are greater than 90 minutes is below 3%.

The SARPs of normal flight tracking recommended that if somehow one tracking position report is missed followed by the next position report reaching the ground tracking system on time successfully, then this scenario can be treated as a ‘restored 4D/15 tracking’ and should no further actions and/or procedures to be provoked. 47% of the gaps occurred in the demonstration belongs to this case.

The times of tracking gaps’ occurrence during the demonstration counting by day are shown as Figure 4.

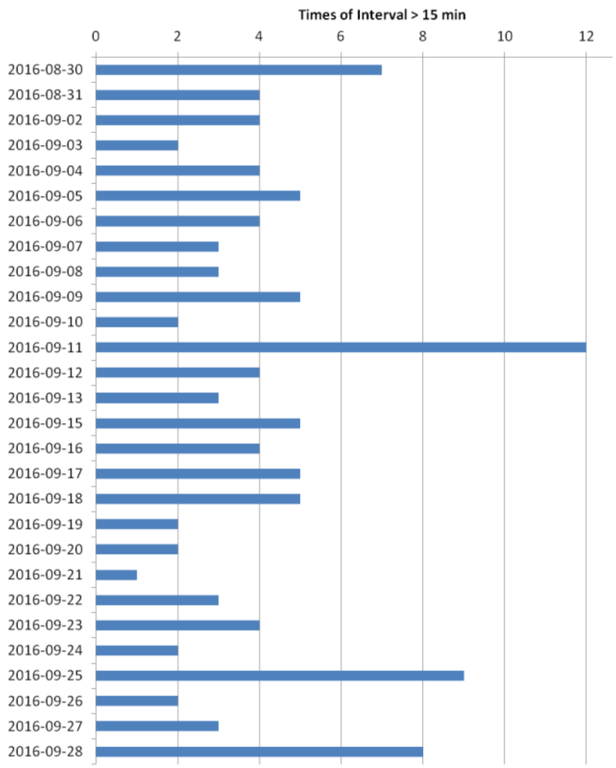

Figure 4 Counts of Tracking Gaps by Day

It suggests that during the most days of demonstration, the occurrences of gaps are not greater than 4 times a day, only 4 days exceeded 6 times, and there was the one and only day, September 11th 2016, which 12 times of 11 flights occurred. The average occurrence frequency is around 3.77 per day for the whole demonstration of 31 days.

For the all 41 routes participated in the demonstration, there are 13 routes who achieved full 4D/15 tracking coverage throughout the whole demonstration. The counts of 4D/15 tracking gaps what the other 28 routes encountered are shown in Figure 5.

And the cumulative time of gaps for each flight is shown in Figure 6.

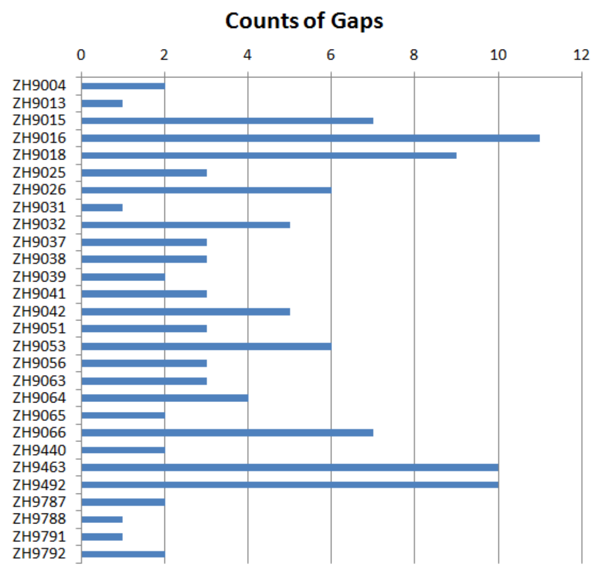

Figure 5 Counts of Tracking Gaps by Route

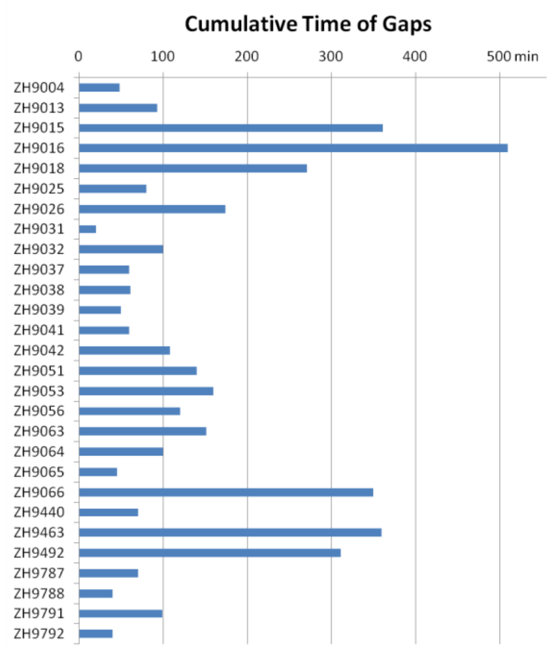

Figure 6 Cumulative Time of Gaps

The total time of gaps in the whole demonstration, by summing up the cumulative time of gaps for each route, is 5087.58 minutes, while the overall operation time of the demonstration is 129156.27 minutes. Then the time ratio of flights fulfill the 4D/15 tracking requirements can be obtained by

$$R_{4D/15\ tracking} = 1 - \frac{\sum_{i=1}^{N} t_{i\ cum.gap}}{\sum_{i=1}^{N} t_{i\ opt.}} \qquad (7)$$

where $t_{i\,cum.gap}$ denotes the cumulative time of gaps of the i^th^ flight and $t_{i\,opt.}$ refers to the operation time of the i^th^ flight. Thus over 96.06% of operation time for the whole demonstration is fulfilled the 4D/15 tracking requirements.

A more detailed analysis has also been being conducted to the gaps of 4D/15 tracking. It is found that some gaps are sporadically occurred, such as Flight ZH9004 encountered the two gaps among its 25 operations during the demonstration (Figure 7 (a)), the gaps were either at the same place or on the same day, and were both shorter than 30 minutes (yellow lines in Figure 7 (b)). This kind of gaps places only little effects on normal flight tracking and may not be eliminated since the cause could be random and various.

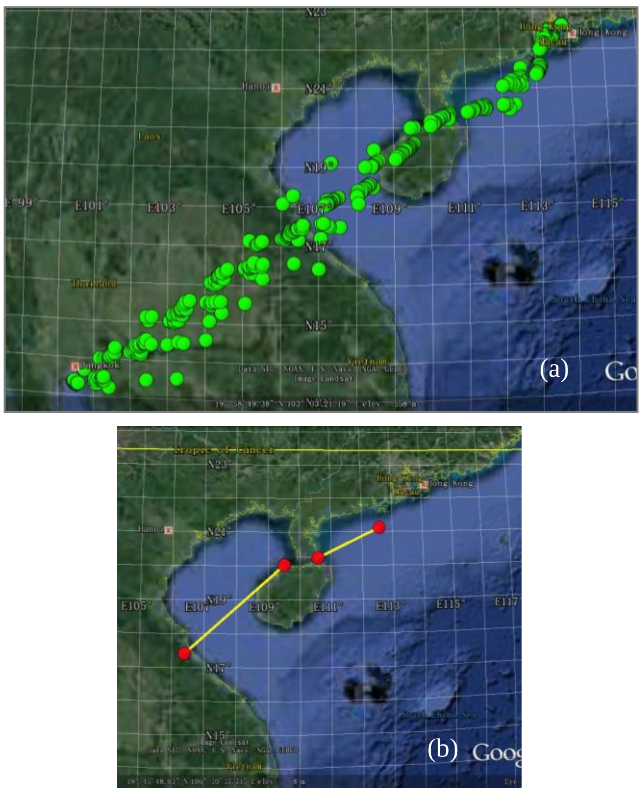

Figure 7 (a) Tracking Reports of Flight ZH9004

(b) Tracking Gaps of Flight ZH9004

Meanwhile, some of the gaps act in aggregated manners of space and time. Figure 8 show that the Flight ZH9015 and ZH9016 encountered normal flight tracking gaps in the same region. The yellow lines denotes that the tracking gap duration is less than 30 minutes, the orange lines suggests that the tracking gap is between 30 to 60 minutes, and the red lines means that the gap time is greater than 60 minutes.

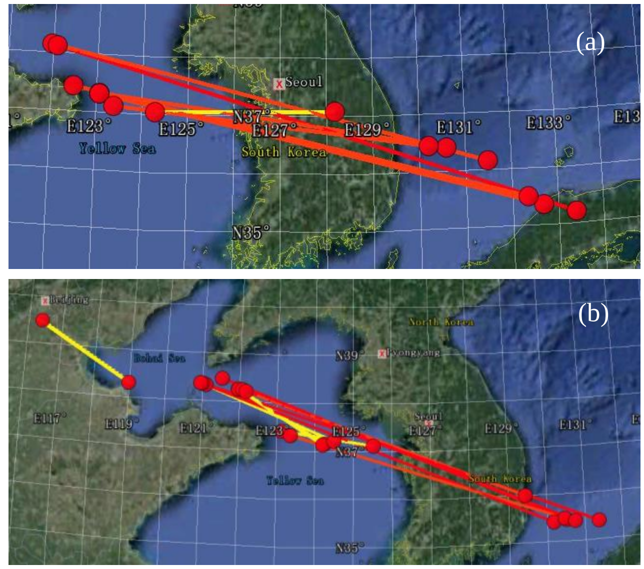

Figure 8 (a) Tracking Gaps of Flight ZH9015

(b) Tracking Gaps of Flight ZH9016

A risk assessment measures would be an effective way to deal with such kind of gaps in both pre-flight and in-flight stages. Operators need to establish corresponding mitigations for this scenario such as using voice or other communication systems to ensure that the flight remains in the normal operation.

5. SUMMARY

A regional demonstration for normal flight tracking using ACARS position reports had been carried out by Shenzhen Airlines from August to September of 2016. 41 routes and 763 flights were participated in this demonstration. The statistics shows that the overall 4D/15 tracking conformity rate is over 96% during the demonstration using ACARS position reports. Gaps analysis has been being conducted to obtain a better understanding of the tracking gaps and will help the operator to improve its normal flight tracking capability via risk assessment and management.

6. ACKNOWLEDGMENTS

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