

# Data Reception Analysis of ADS-B on Board the TianTuo-3 Satellite

Lihu Chen<sup>1</sup>, Sunquan Yu<sup>1,\*</sup>, Quan Chen<sup>1</sup> and Yong Zhao<sup>1</sup>

<sup>1</sup> College of Aerospace Science and Engineering, National University of Defense Technology, Changsha, Hunan, China

\*Email: yusunquan12@nudt.edu.cn

**Abstract.** Aircraft information can be easily integrated to Internet of Things by ADS-B technology. The spaceborne ADS-B receiver equipped with TianTuo-3 satellite has realized China's first aircraft surveillance from space, it has been working well and stably receiving over 100 million ADS-B messages from global aircraft during last four years. In this paper, the data obtained by the TianTuo-3 ADS-B receiver is analysed in detail, including statistical analysis on the detection probability, the proportion of all types of aircraft, the increasing rate of aircraft in the world. These results demonstrated that satellite ADS-B system provides an all-around safety and surveillance to air traffic management, and it can help in rescuing, surveying, or tracking of special aircraft, or analysing world flight for economic studies.

## 1. Introduction

Automatic Dependent Surveillance-Broadcast (ADS-B) system has become one of the hotspots in the field of aviation surveillance in recent years because of its huge civil value and potential military value [1]. With the vigorous development and maturity of space technology, especially micro-satellite technology, satellite-based ADS-B system provides the possibility for large-scale, all-weather, all-time aviation monitoring services, which can avoid the aviation losses like Malaysian Airways MH-370 and Air France AF-447 [2]. Due to its outstanding performance, many countries and regions mandated that new aircraft should be equipped with ADS-B [3,4,5].

The world's first satellite PROBA-V with ADS-B receiver was launched on May 7th, 2013, which verifies the feasibility of on-board detection of ADS-B signals. Because of the great advantages of spaceborne ADS-B, many countries and organizations have invested in research. Dozens of satellites carrying ADS-B receivers have been launched, such as GOMX series satellites [6,7], STU-2 satellites [8], TianTuo-3 [9] and Iridium-NEXT satellites. Among them, the Iridium-NEXT has completed 66 satellites deployments and become the first constellation achieving global aviation surveillance [10].

China's first ADS-B satellite TianTuo-3, which was developed by the National University of Defence Technology (NUDT), carries a high sensitivity space-borne ADS-B receiver as one of the most important payload elements. After launch on 20 September 2015, it can receive 400,000 messages per day at most. Now it has been working for more than 4 years and has obtained a total of 107,268,827 effective messages.

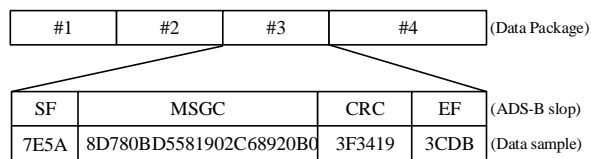


## 2. Data format and overview of TT3-ADS-B

### 2.1. Data Format

Figure 1 shows the data format given by the TianTuo-3-ADS-B receiver, which consists of 14 Bytes: Start Flag (SF, “7E5A”), Message Content (MSGC), Cyclical Redundancy Check (CRC) code and the End Flag (EF, “3CDB”).

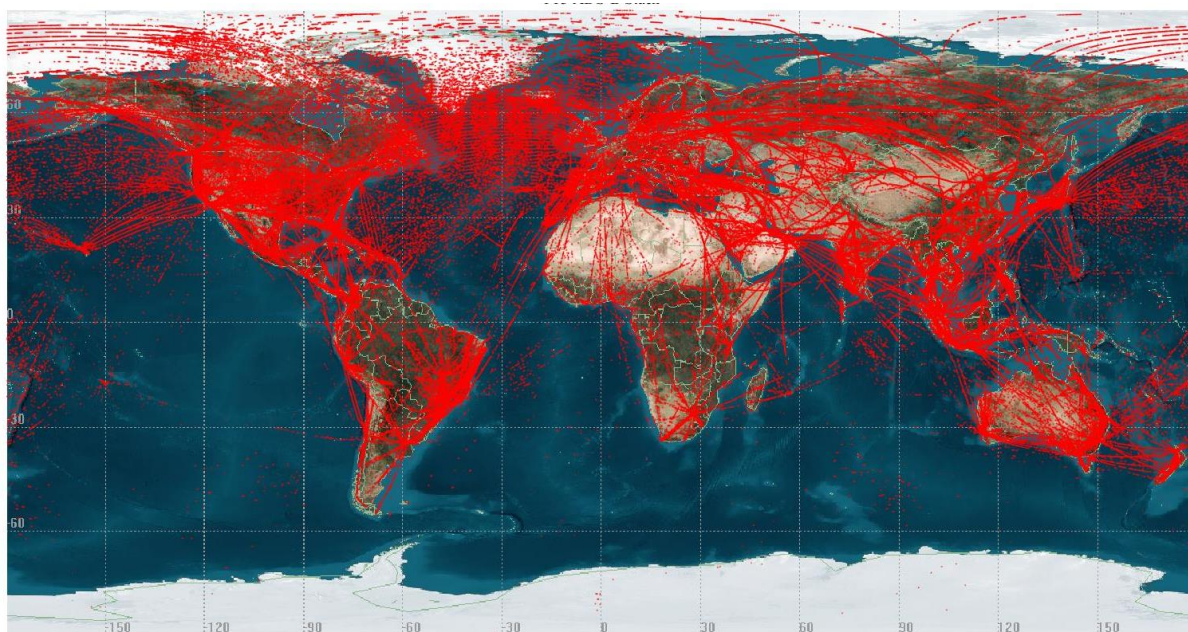
Figure 2 shows an example of decoded data collected by TT3-ADS-B on 21 September 2015, including: the Message ID, the CRC result, the Downlink Format (DF), the Capacity field (CA), the 24-bit ICAO (The International Civil Aviation Organization) Announced Address (AA), the Type Certificate, the Altitude, the coordinate time in Coordinated Universal Time (UTC) seconds, the Longitude, the Latitude, et al.



**Figure 1.** TT3 ADS-B data packet composition and format.

ID	Message	CRC	DF	CA	ICAO24	TC	Vehi
1	8D780BD5581902C68920B03F3678	0	17	5	780BD5	11	NoDa
2	8D780BD5581902C68920B03F3678	0	17	4	780BD5	7	NoDa
3	8D4245A699057217680A2098CD3D	0	17	5	4245A6	19	NoDa
4	8D7802799945589A20042D6EC6EA	0	17	5	780279	19	NoDa
5	8D78072A58810314627B0CDD75BF	0	17	5	78072A	11	NoDa
6	8D78078158AFC23ACB5B5F4194E4	0	17	5	780781	11	NoDa
7	8D4245A699057217680A2098CD3D	0	17	5	4245A6	19	NoDa
8	8D7802799945589A20042D6EC6EA	0	17	5	780279	11	NoDa

**Figure 2.** TT3 ADS-B data packet composition and format.



**Figure 3.** Static distribution of global aircraft obtained from TT3-ADS-B dataset in May 2018.

### 2.2. Data overview

Figure 3 shows the position of all the ADS-B messages received in May 2018. It is obvious that there are many aircraft flying on the main air-route channels, including the North Atlantic, North America, East Asia, et al.

Table 1 shows the number of all the ADS-B messages in different types. The airborne velocity and airborne position messages account for 79%, which are the crucial information for air traffic, while these two types of messages should account for 66% for A2 and A3 class transmitters according to the ADS-B standard. For A0 and A1 class transmitters, the target and status information are unnecessary, therefore the ratio of position and velocity messages is larger than 66% [1].

**Table 1.** Message number received by TT-3.

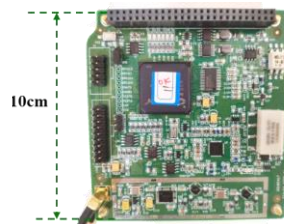
Message Type	Number Received	Percentage
Total	107268827	100%
Airborne Velocity	41171052	40.09%
Airborne Position	39941286	38.89%
Surface Position	10782481	10.50%
Identification and Category	6144700	5.98%
Operational Status	2814564	2.74%
Target State and Status	194191	0.19%
Others	1650646	1.61%

### 3. Receiving ability analysis

In design, the TT3-ADS-B receiver implements a 10cm×10cm Printed Circuit Board (PCB) to integrate all the RF and digital modules, because this size can be easily assembled in the CubeSat [11]. The Bifilar Helical Antenna is used to collect signals transmitted by aircraft from thousands of kilometres away and the antenna gain is 5dBi. Figure 4&5 shows the ADS-B receiver and antenna on the TianTuo-3.

#### 3.1. Coverage swath analysis

Figure 6 shows the sketch map for detection width analysis of TT3-ADS-B, which can achieve 2545km by single antenna. The longitude and latitude information are obtained from messages received by TT3-ADS-B receiver. For 496km height satellite, the half width of antenna beam is 63 degree. It is worth noting that the detection range of ground ADS-B station is only about several hundred kilometres or even shorter, and it depends on the geometrical factors and receiver's sensitivity. The TT3-ADS-B receiver can detect the signal above -93dBm level.

**Figure 4.** The ADS-B receiver on TT-3.**Figure 5.** The ADS-B antenna on TT-3.**Figure 6.** Sketch map for detection width analysis of TT3-ADS-B.**Figure 7.** An example of detection probability analysis for TT3-ADS-B.

### 3.2. Detection probability analysis

The pursuit of higher detection probabilities is one of the important aims of developing it. Werner K defines the probability of detection (POD) as the percentage ratio between the actual number of position messages received and the expected number of position messages [5]. Since they use the ground station data to calculate detection probability, it is difficult to get the result when those data are hard to acquire. In this paper, we propose a method to calculate detection probability with only data from ADS-B satellite itself, and the analysis process will be easier and quicker.

The detection probabilities of space-borne ADS-B ( $P_{ADS-B}$ ) can be defined as the ratio of the number of messages received by the space-borne ADS-B ( $N_{rx}$ ) to the number of messages transmitted by aircraft ( $N_{tx}$ ), i.e.,  $P_{ADS-B} = N_{rx}/N_{tx}$ . The number of messages transmitted by aircraft can be calculated as:

$$N_{tx} = v_{tx} \cdot \Delta t \quad (1)$$

Where  $v_{tx}$  equals to 3.1 messages per second. The time interval is expressed as total length of path covered ( $d$ ) divided by the velocity of aircraft ( $v_{aircraft}$ ):

$$\Delta t = v_{aircraft} / d \quad (2)$$

The total length of path can be obtained by ADS-B messages. once the start position ( $x_1, y_1$ ) and end position ( $x_2, y_2$ ) is decoded, the distance can be given by:

$$d = R_e * \arccos[\cos(y_1) * \cos(y_2) * \cos(x_1 - x_2) + \sin(y_1) * \sin(y_2)] \quad (3)$$

Where  $x_1$  and  $x_2$  are longitude, and  $y_1$  and  $y_2$  are latitude. It is worth noting that the track with longer duration should be selected in order to get a more accurate result. Furthermore, the flight state should be flying rather than taking off or landing on, because a constant speed is helpful to estimate the flight time interval.

Figure 7 shows an example of detection probability analysis for TT3-ADS-B. The TT3 space-borne ADS-B has obtained 78 messages of an aircraft whose ICAO address is 861B64 when satellite was above Fuji, Japan. The update interval is about 10 seconds, which enables it real-time tracking.

After decoding the messages, we can know that the start position is located at 35.164°N and 138.821°E, and the end position is located at 35.110°N and 138.606°E. the distance is 20474 meters between these two points. We can acquire the velocity from the messages the velocity is 336 miles per second. The time interval for obtaining information continuously is 136 second. Since this aircraft has transmitted 421 messages, the detection probability is 18.5%.

Through the method described above, table 2 gives detection probability analysis in some other representative areas. The detection probability varies from 4.52% to 64.53% by different areas.

**Table 2.** Detection probability analysis of TT-3 ADS-B in some typical areas

ICAO Number	Start Position	End Position	Duration (Second)	Probability
76CEC6	37.9519°N, 138.1345°E	38.3335°E, 138.4715°E	204	43.99%
E49231	-10.5930°S, -36.7155°W	-10.5314°S, -36.6646°W	98	36.18%
4007F3	50.5894°N, -60.6351°W	50.7029°N, -62.4530°W	664	4.52%
4B16C8	54.3672°N, -9.2816°W	54.4577°N, -9.5645°W	92	64.52%

### 3.3. Statistical results

Figure 8 gives the number of ICAO 24-bit address from 2016 to 2018. According to the rules of ICAO, each aircraft has its unique ID number, thus an ICAO ID is corresponding to a specific aircraft. The increase of ICAO count actually indicates the expand of global aircrafts. Based on the variation of ICAO



number, the number of aircraft in 2017 has soared by nearly 20% compared with 2016. According to the forecast of Boeing, in the next 20 years, up to 38,050 aircrafts will be needed [12], which brings tremendous pressure to aviation surveillance. Thus, it is necessary to constantly upgrade technology of traffic surveillance and management to meet future needs.

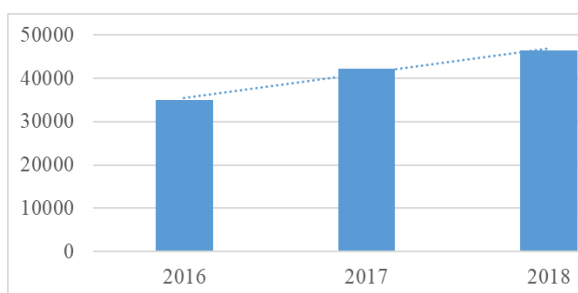
Aircraft broadcasts its status information to air control management center through ADS-B messages. These messages not only contain information about the position and speed of the aircraft, but also include detailed categories, carrying capacity, application, fuel volume, and communication status. Figure 9 illustrates the emergency messages received by TT3-ADS-B in three years, where lifeguard/medical, minimum fuel and unlawful interference emergency occupy the most majority. It is worth mentioning that ADS-B emitter system automatically receives the signals from global navigation system and broadcasts its status information, which are held independent of man-made malicious interference, otherwise warning messages will be sent automatically. Thus, the received “Unlawful Interference” messages verify the effectiveness of this alarming mechanism.

ADS-B emitters can be divided into four levels according to the different transmitting power (A0, A1, A2, A3). Class A3 is equipped on the common large airliner, which has the largest transmission power and the largest number of installed ADS-B. According to figure 10, messages from A0 transmitter are received by TT3-ADS-B receiver, which is beyond our expected design performance. The initial link budget in the design stage is only intend to receive A3 messages, but A0 messages with 1/3 power of A3 signals are also successfully received and decoded. It may be caused by the aircraft antenna pattern which has over 0dB gain in some directions, while it is assumed to be omnidirectional in link budget. Also, it may indicate that some A0 transmitters transmit power far greater than 70W.

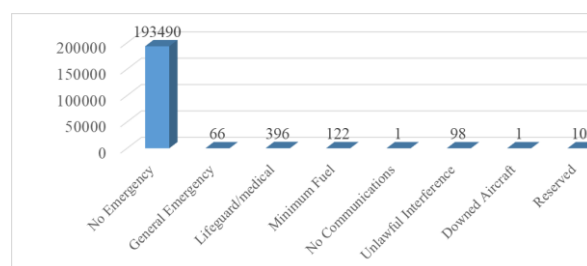
Figure 11 to 13 respectively illustrate received messages composition by the ADS-B Aircraft Emitter Category according to three classification criteria of DO-260B. Set A is classified by weight. For example, aircrafts are classified to Light (less than 15500lbs), Large (15500lbs ~ 300000lbs) and Heavy (heavier than 300000lbs). The data in Figure 11 shows that Large and Heavy aircrafts cover the largest proportion. Because ADS-B is still in the promotion stage, priority should be given to large passenger and cargo aircrafts to enhance their safety. Also, it can be predicted small aircraft will be gradually equipped with ADS-B in the near future.

Set B specially refers to aerostats, gliders and other engines-free aircraft. According to Figure 12, most of Set B are light-than-air with 3073 messages, covering 2/3.

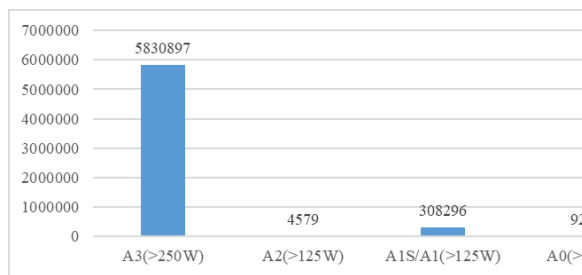
Set C consists of emergency vehicles, service vehicles and obstacles such as tethered balloons. These information helps aircraft to avoid obstacles automatically and suggests that ADS-B achieves the full range of safety and surveillance of air traffic.



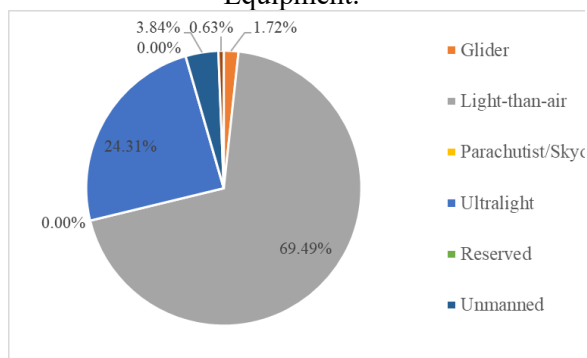
**Figure 8.** Numbers of unique ICAO 24-bit address in 2016, 2017 and 2018.



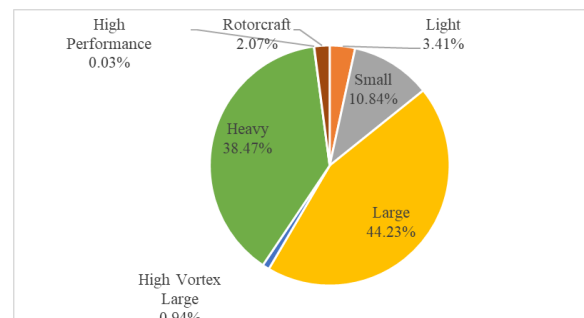
**Figure 9.** Numbers of “Emergency/Priority Status” subfield in aircraft status messages.



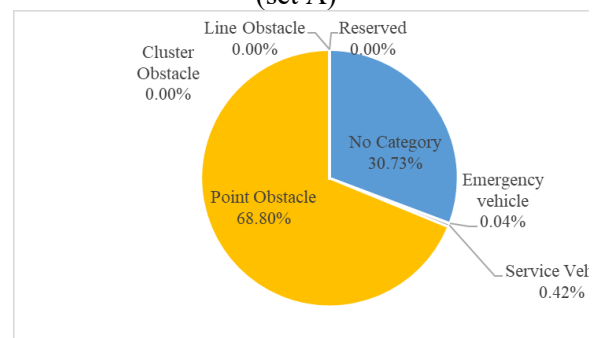
**Figure 10.** ADS-B Class A Transmitter Equipment.



**Figure 12.** ADS-B Aircraft Emitter Category (set A)



**Figure 11.** ADS-B Aircraft Emitter Category (set A)



**Figure 13.** ADS-B Aircraft Emitter Category (set A)

#### 4. Conclusion

The TianTuo-3 ADS-B receiver with high sensitivity has a large coverage on the ground. The authors analysed the data obtained by the ADS-B receiver during the September 2015 to the December 2018 in detail. The results include: (1) The coverage swath of TT3-ADS-B can reach to 2545km, which enlarges the detection range by dozens times of that of ground station; (2) With maximum updating data rate of only about 10 seconds, TianTuo-3 ADS-B can achieve a real-time tracking to a single aircraft whe; (3) With over 100 million messages, we give the detailed analysis results of aircraft in recent 3 years. These results demonstrated that ADS-B system provides an all-around safety and surveillance to air traffic management.

#### Acknowledgments

This research has been supported by the National Key Research and Development Program of China under grant 2016YFB0502402.

#### References

- [1] RTCA, "Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment," *DO-181D. Radio Technical Commission for Aeronautics*, Washington DC, USA, 2008.
- [2] Ashton, C., Bruce, A. S., Colledge, G. and Dickinson, M, "The Search for MH370," *The Journal of Navigation*, 68(1), 1-22, 2015.
- [3] European Union, "Laying down requirements for the performance and the interoperability of surveillance for the single European sky," *COMMISSION IMPLEMENTING REGULATION*, EU, No 1207/2011, 35-52, 2011.
- [4] Blomenhofer, H., Pawlitzki, A., Rosenthal, P. and Escudero, L, "Space-based automatic dependent surveillance broadcast (ads-b) payload for in-orbit demonstration," *Advanced Satellite Multimedia*

- Systems Conference (ASMS) and 12th Signal Processing for Space Communications Workshop (SPSC)*, Baiona, Spain, September 5-7. IEEE, 2012.
- [5] Werner, K., Bredemeyer, J. and Delovski, T., “ADS-B over satellite: Global air traffic surveillance from space,” *Digital Communications-Enhanced Surveillance of Aircraft and Vehicles (TIWDC/ESAV)*, Rome, Italy, September 15-16. IEEE, 2014.
- [6] Alminde, L., Christiansen, J., Kaas Laursen, K., Midtgaard, A., Bisgard, M., Jensen, M., Gosvig, B., Birklykke, A., Koch, P. and Le Moullec, Y., “Gomx-1: A nano-satellite mission to demonstrate improved situational awareness for air traffic control,” *26th Annual AIAA/USU Conference on Small Satellites*, Logan, August 13-16, 2012.
- [7] Gerhardt, D., Bisgaard, M., Alminde, L., Walker, R., Fernandez, M. A., Latiri, A. and Issler, J. L., “GOMX-3: Mission Results from the Inaugural ESA In-Orbit Demonstration CubeSat,” *30th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, August 6-11, 2016.
- [8] Wu, S., Chen, W. and Chao, C., “The STU-2 CubeSat Mission and In-Orbit Test Results,” *30th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, August 6-11, 2016.
- [9] Li, S., Chen, X., Chen, L., Zhao, Y., Sheng, T. and Bai, Y., “Data Reception Analysis of the AIS on board the TianTuo-3 Satellite,” *The Journal of Navigation*, 70(4), 761-774, 2017.
- [10] Garcia, M. A., Dolan, J. and Hoag, A., “Aireon's initial on-orbit performance analysis of space-based ADS-B,” *Integrated Communications, Navigation and Surveillance Conference (ICNS)*, Herndon, VA, USA, April 18-20. IEEE, 2017.
- [11] Swartwout, Michael, “The First One Hundred CubeSats: A Statistical Look,” *Journal of Small Satellites*, 28 November, 2015.
- [12] Boeing Co., “Current Market Outlook 2015–2034,” 2015.