Aircraft monitoring by the fusion of satellite and ground ads-b data

Xuan Zhang[a], Jingjing Zhang[b], Shufan Wu[a],Qian Cheng[b], Rui zhu[b]

[a] *Shanghai Engineering Centre for Microsatellites*
Chinese Academy of Science, Haike Road 99,
Pudong District, Shanghai 201203, P.R.China

[b] *VariFlight,*
Hefei, Anhui Province, P.R.China,

---

microsat

SECM

microsat

- Shanghai Engineering Center for Microsatellites
- Founded by Chinese Academy of Science (CAS) and Shanghai City Government
- Located in Pudong of Shanghai
- Has a capability to manufacture 20+ satellites simultaneously

AIT Area | KM3 | 20T Vibration table

SECM

microsat

Missions

Navigation	Micro/Nano satellite	Science	Others
Nav-1 (2015) [ca.900kg]	BX-1 (2008)	TanSAT(2016, 600kg)	
Nav-2 (2016)	STU-2 (2015) [3U,2U CubeSat]	DMaHS(2016, 1800kg)	
	BX-2 (2016) [50kg]	QUESS (2016, 500kg)	

Over past 10 years, SECM has launched into orbit 9+ micro/small satellites, accumulated 30+ orbit-year of satellite operation.

VariFlight

- VariFlight was established in 2005, dedicated to the development of specialized products and technologies for China' s civil aviation industry and helping customers increasing operational efficiency at all fronts.

- At VariFlight, data is fundamental to everything. Having years of expertise and incomparable aviation data, VariFlight provides the insight to understand the industry, drive growth and manage risk.

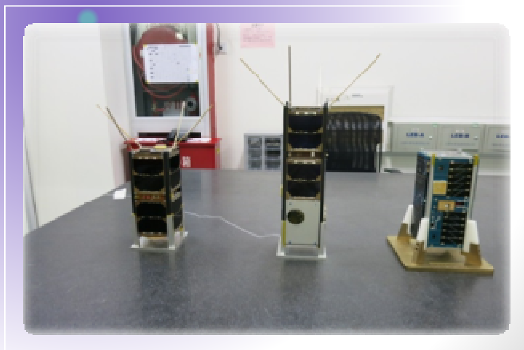
STU-2 Mission

Two 2U CubeSat and One 3U CubeSat

- Monitor civil aircraft traffic information via ADS-B receiver
- Monitoring sea ice status in polar regions
- Gaining the maritime traffic information via AIS receiver
- New technology demonstration & validation of Micro-propulsion, dual-band GPS-BD receiver, and Gamalink
- Demonstration of autonomous rendezvous (RVD) flight

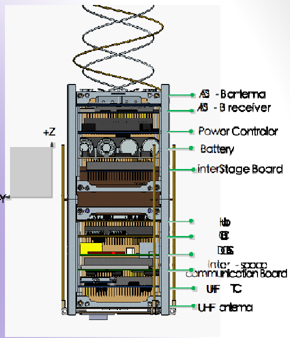

STU-2 Mission

- 3 Cube Satellites to carry different payloads
- 2 Ground Stations in Shanghai and Nanjing of China
- Orbit: SSO, 480km, 8:00am
- Launch: Sept 25th 2015
  Jiuquan, China



STU-2C

- Platform: OBC, ADCS, Structure, Power Controller and Battery, and TTC.
- Payloads:
  - ADS-B receiver
  - SoC dual-band GPS/BD2 receiver
  - a minimized magnetometer
  - a multi-channel inertial sensor
  - Inter-space communication Board



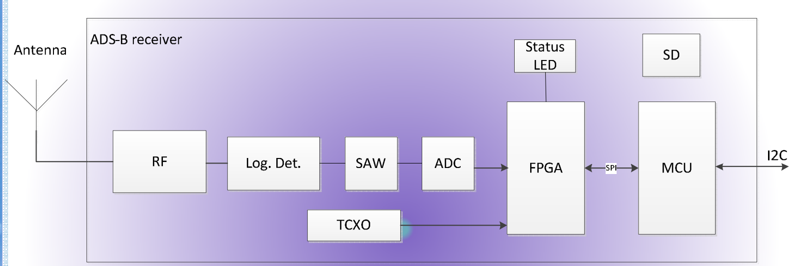
Space ADS-B overview

A radio link between ADS-B-aircraft and the satellite should be considered at the very first.

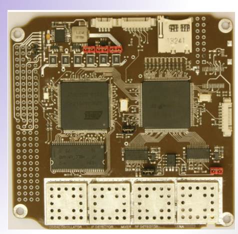
parameter	value	unit
TX power	24 / 250	dBW/ W
TX antenna gain	1	dB
Line Loss	2	dB
TX Bit rate	1.04	Mb/s
EIRP	23	dBW
Atmospheric gasses loss	2.5	dB
Polarization loss	6	dB
RX antenna gain	5	dB
RX sensitivity	-103	dBm
Max Range	925	km

The link budget is calculated based on the assumption that we have antenna with higher gain and the receiver with higher sensitivity than the ground device. And the supposed maximum range is figured out to be quite sufficient for this mission with orbit of 480km.

ADS-B receiver



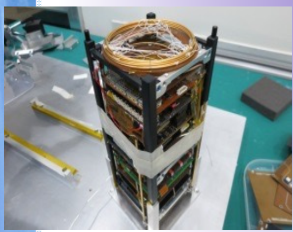
- A SDR receiver
- Provided by Gomspace
- RF: demodulation
- FPGA: Symbol decoding and packet checksum
- MCU: Packet decoding and data storage
- 1090ES standard
- Sensitivity < -103 dBm
- Power consumption: <600mW



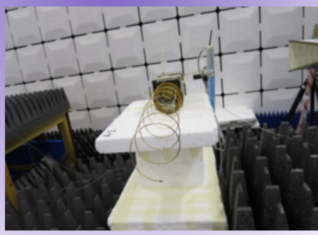
Antenna

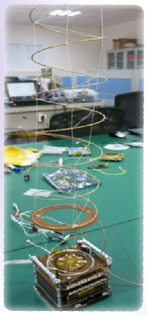
microsat

- A helical antenna which can be stowed to fit on the end of a standard CubeSat structure is used for space receiving
- Center Frequency : 1090MHz
- RHCP
- Peak gain: 8.8 dBi
- Beamwidth (3 dB, half angle) : around 22 degree



Antenna for ADS-B stowed



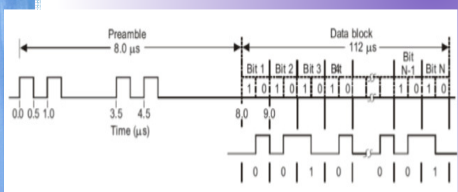


Antenna for ADS-B deployed

Ground test

microsat

- The ADS-B message has an 8 bit preamble followed by the data block of 112 bits. The message containing aircraft ID, position and velocity is modulated BPPM, and the BPPM signal is modulated by ASK.
- In order to simplify the test and save cot, the modulated ADS-B signal can be simulated by vector signal generator when specific parameters are set.
- A commercial ADS-B antenna with a length of 2 meters is used in the ground test. Left the antenna with a gain of 9 dBi near the window, the receiver can obtain hundreds of messages in an hour.



ADS-B message

Parameter setting for ADS-B simulation

parameter	value
Device type	Keysight N5172B
Frequency	1090MHz
Mod type	ASK
Filter	RNYQ (alfa=1.00) EVM
SymRate	2Msps
Data	User File (ADS-B @BIT) which specify messages with known plane position and ID information
Trig Type	Continuous (Free Run)

In orbit result

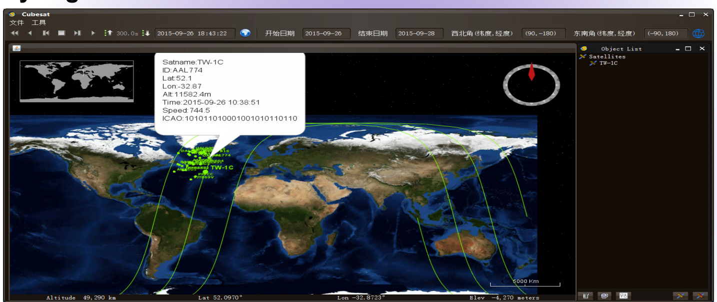
microsat

- On the second day after the launch, Sept 26th 2015, when the STU-2C passes over Shanghai ground station at 18:15pm, the deployment of the helical antenna is successful.
- After the deployment, the ADS-B receiver on board the CubeSat was switched on via tele-command for first trial. Immediately the STU-2C captured ADS-B signals transmitted from 16 aircraft flying under the satellite. Since then the receiver has successfully received over 132425 ADS-B signals from 19381 aircrafts (Based on data collected by 10th Jan, 2016).
- The SD card which is mean to store the data collected by the payload did not work well in space and we have to depend on the limited space in the RAM which only can store less than 2000 messages each time.

In orbit result

microsat

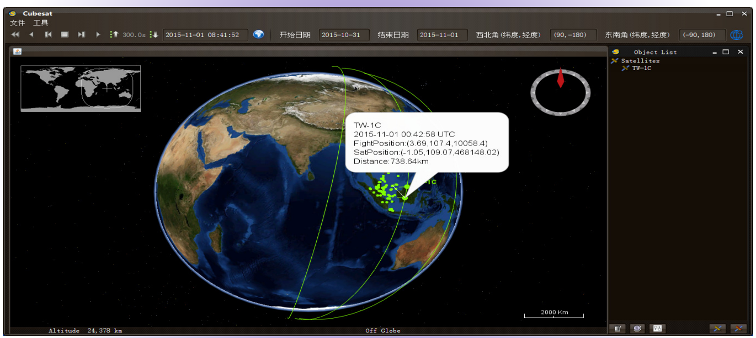
- The software to display the decoded ADS-B messages has been developed by Shanghai Carbon Data Research Center for better analyzing the in-orbit data.



- The STK like display software can show the position (green spots in the window stand for the specific position of the plane be heard) of plane messages in real time with the STU-2C flying according to the orbit (green line in the window indicates the trajectory of the STU-2C) propagated by TLEs imported.
- The information like plane ID, latitude, longitude and altitude, speed, and the moment be heard is well shown in the window (2D or 3D) when we point to a spot with arrow.

In orbit result

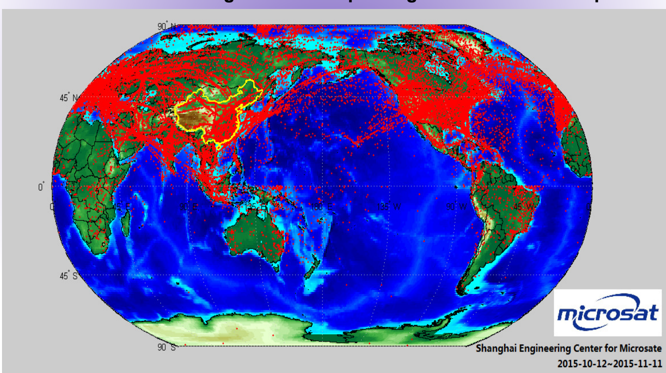
- when we click a specific spot, the distance between the plane and STU-2C at the moment is calculated to give user a brief impression of the link budget



- Based on the telemetry of the max number of frames for the receiver to decode is 182 every 10 seconds, and minimum number could be zero during the pass of some the oceans. The distance between the plane heard and the satellite (STU-2C) can reach 1500km which can indicate the sufficient of the link budget.

In orbit result

- Accumulative data of one month (2015/10/12-2015/11/11) could give us a brief compression of the most busy air traffic like the European, the North of American and the East of Asia. Several routes across continents could be clearly seen from the map.
- In sharp contrast, the ADS-B messages heard from southern hemisphere is so rare and is not so realistic although in generally air traffic in South African and South American is much less than the northern part. RAM storage may be the greatest cause which makes the receiver has no space to record the data during the satellite passing the southern hemisphere.



aircrafts distribution captured by STU-2C
(data obtained from 2015/10/12-2015/11/11 UTC)

The fusion of space data and ground data

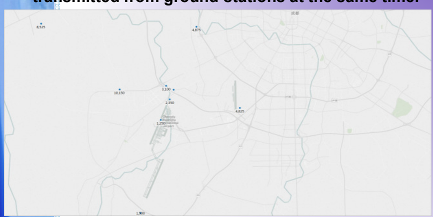
- A space-based ADS-B system for aircraft tracking has obvious advantage compared to ground ADS-B when we compare the in-orbit data with the ground ADS-B data provided by VariFlight Technology in China. A sample (10/12/15-30/12/15) of 41,433 messages taken from the data collected by STU-2C yields the following conclusion.

- It provides a powerful sense of consistency when compared with the data collected by ground stations. One thing worth mentioning is that 52% of the data from CubeSat is also received from ground stations, leading to a conclusion that space-based ADS-B is bringing the reliability of satellite-based surveillance data and it is possible to monitor flights' tracks by satellites.

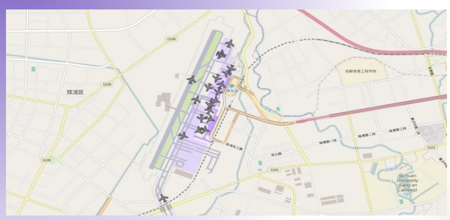
The fusion of space data and ground data

- A very interesting phenomenon is that only 13.6% of the space-based messages are acquired below an altitude of 10,000 feet.
- The main reason is that ADS-B signal is easily disrupted by mountains, buildings and other obstacles.
- This satellite-based data collection may be less effective than ground-based ADS-B stations for mountainous areas, especially for some business districts where millions stations have been located to guarantee the safety during the taking-off and landing of the flights.
- Example :

STU-2C has coincidently recorded some flight messages when it passed over Chengdu ShuangLiu International Airport which is located in Sichuan Province surrounded by mountains. And only several airplanes were near the airport according to the record by satellite. However, signals are continuously transmitted from ground stations at the same time.



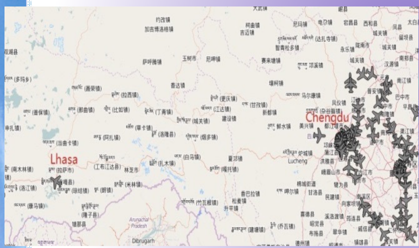
The space-based ADS-B data provided by VariFlight near Chengdu Shuangliu International Airport



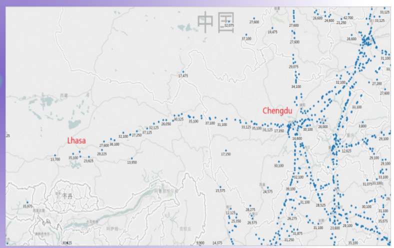
The ground based ADS-B data near Chengdu Shuangliu International Airport

The fusion of space data and ground data

- In regions with little ground-based equipment, space-based system shows its irreplaceable advantage. Here we take the air route from Chengdu to Lhasa as an example. Due to the special topography of Tibet, it is nearly impossible to build ground stations along this air route.



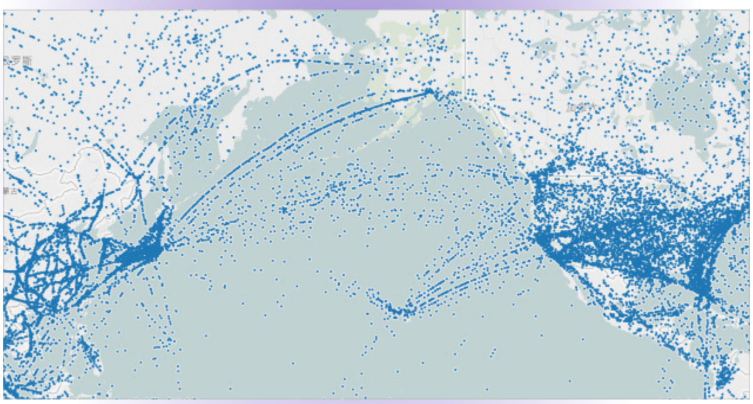
The ground based ADS-B data provided by VariFlight near CHENGDU and Lhasa



The space based ADS-B data (by STU-2C) near CHENGDU and Lhasa

The fusion of space data and ground data

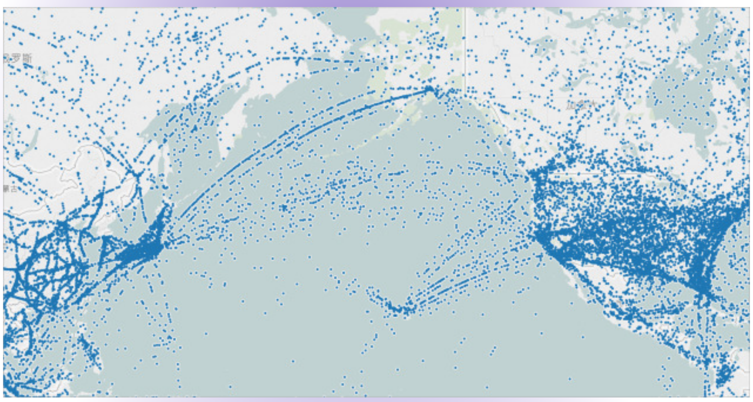
- When we combine the ground data with satellite data, we have a whole view of the flight situation. The air routes are clear and are matched well with the air routes report data



Combination of the data from CubeSat and ground stations

The fusion of space data and ground data

- When we combine the ground data with satellite data, we have a whole view of the flight situation. The air routes are clear and are matched well with the air routes report data



Combination of the data from CubeSat and ground stations

The fusion of space data and ground data

- We assume that we have a global system consisting of several CubeSats which share the same performance with STU-2C. Then a 77.52% of coverage by space-based ADS-B can be approaching, which is approximately the same percentage of aircrafts installed ADS-B equipment globally. The rough statistics indicates an efficient solution to fill in current radar coverage gaps and obtain a full global coverage in the near future.

- In summary, the data collected by satellites and ground stations has its own advantages and disadvantages. The ground based data is more useful where the flights are taking off or landing or sliding, while the space based data can cover a large number of regions where the ground station is hard to place, like oceans, polar area and other no man's lands. If these two kinds of data can take each other as a complementary, then the data will be more complete and can supply for some special application areas.


microsat
Thank you!
Prof Dr Shufan Wu
Chinese Academy of Science(CAS)
Shanghai Engineering Centre for Microsatellite
Email: shufan.wu@mail.sim.ac.cn
Tel：021-50735022，15800537342