CubeSat Constellation Design for Air Traffic Monitoring

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ADS-B for Aircraft Tracking

- ADS-B = Automatic Dependent Surveillance - Broadcast

- Emitted from the aircraft's Mode-S transponder

- *Surveillance* data includes aircraft position, velocity, and altitude, as determined by GNSS, navigational intent and meteorological data. Info is *automatically* transmitted periodically without flight crew or operator input. Transmission is *dependent* on proper operation of on-board equipment.

- Currently tracked by ground-based receivers but not over remote oceans or sparsely populated regions such as Alaska or the Pacific Ocean.

- Problematic due to big safety bubble requirement + search and rescue bottleneck (MH370, AF449) -> Can Satellite based ADS-B help?

- 70% of the current commercial aircraft fleet is ADS-B equipped + recent decisions taken by EUROCONTROL and FAA mandate that ADS-B be compulsory equipment on all high performance aircraft from 2015 and 2020 respectively.

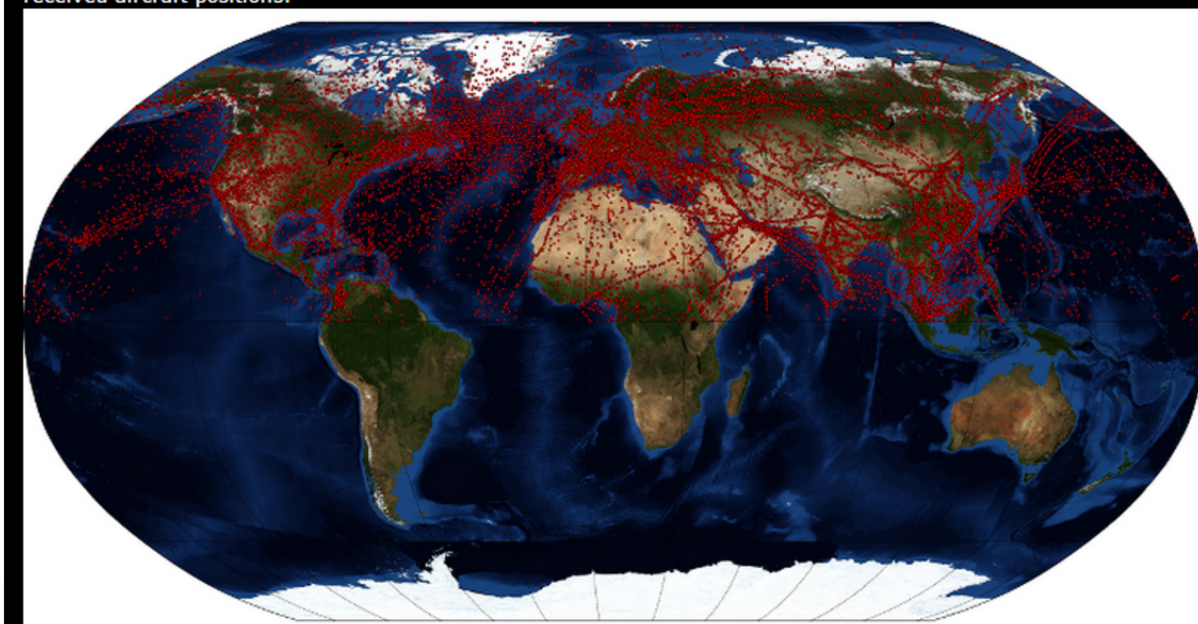
Space-based ADS-B

GOMX-1 was launched 21/11-2013 at 07:10 UTC

GOMX-1 is a 2U cubesat mission developed in collaboration between GomSpace, DSE Airport Solutions and Aalborg University to perform research and experimentation in space related to Software Defined Radio (SDR) with emphasis on receiving ADS-B signal from commercial aircraft over oceanic areas. As a secondary payload the satellite flies a NanoCam C1U colour camera for Earth observation experimentation. The projected is financially supported by the Danish National Advanced Technology Foundation.

Status

GOMX-1 is now fully commissioned. The attitude control system has detumbled the spacraft from rather high tip-off rates, and all deployables including the helical antenna are deployed. Both payloads are in full operational state. The primary payload - a software defined ADS-B receiver - has received a large amount of aircraft signals indicating a better than expected link-budget on the helical antenna. The image below shows a preliminary plot of a few of the received aircraft positions.



- Proba-V showed ADS-B from a 140 kg platform

- GOMX-1 demonstrated ADS-B tracking from a 2U cubesat

- CanX-7 will demonstrate from the 20 cm nanosatellite

- Geostationary services (Inmarsat, MTSAT) available but not over the poles

ADS-B as Constellations

A fully deployed constellation will allow

- Significant reduction in inter-airplane spacing
- Increase usable airspace leading to a predicted 16-fold increase in trans-oceanic flights
- Reduce fuel consumption (and emissions) with informed optimization of routes
- Reduce flight time
- Study is equally applicable if ADS-C is used instead of ADS-B

Nav Canada has reported the reduction of required "safety bubbles" from 60×80 statute miles to 5×5 statute miles over the Hudson Bay, leading to predicted annual fuel savings of $9.8 million/year

GomSpace's GOMX-1

GOMX-Platform

The GOMX-Platform is based on GomSpace's modular systems that can be combined into e.g. One-, Two- or Three Unit cubesat platforms that provide a capable basis for ambitious missions.

Achieving a mission success is all about focusing on results. When building your mission around the GOMX-platform, using One-Step Integration™, you free resources to concentrate on the aspects of the mission that are most important to you.

Applications

- Education and capacity building
- Technology demonstration missions
- Small science missions

Flexibility

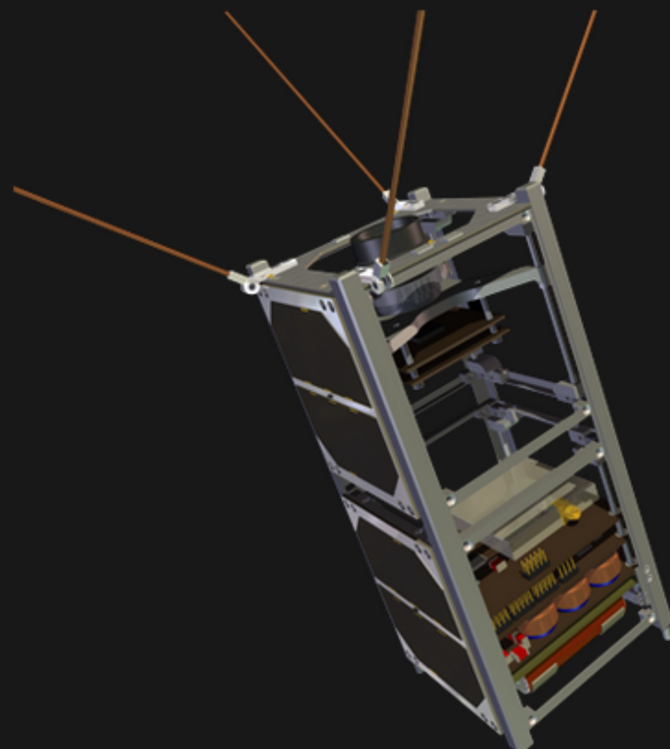
With the GOMX-Platform you get the perfect match for your mission. You can:

- Add you own payload
- Mix with your own platform subsystems
- Mix with subsystems from other vendors
- 1U, 2U, 3U and other versions possible

Compact Earth Observation

Example Configuration

A 2U configuration with camera payload and room for your additional payload.



GOMX-facts:

1U configuration:
- Platform Mass: 725g
- 0.4U available for payload
- Average Input Power: 2.00W*
- Maximum Input Power: 3.8W*
- Average Power Available for Payload: 1.33W*
- Batteries with 21Whr - Integrated on NanoPower P31U

2U configuration:
- Platform Mass: 1200g
- 1.4U available for Payload
- Average Input Power: 3.20W*
- Maximum Input Power: 6.6W*
- Average Power Available for Payload: 2.48W*
- Batteries with 21Whr - Integrated on NanoPower P31U

3U configuration:
- Platform Mass:1500g
- 2.3U available for Payload
- Average Input Power: 4.40W*
- Maximum Input Power: 9.4W*
- Average Power Available for Payload: 3.68W*
- Batteries with 21Whr integrated on NanoPower P and 42Whr on NanoPower-BP4

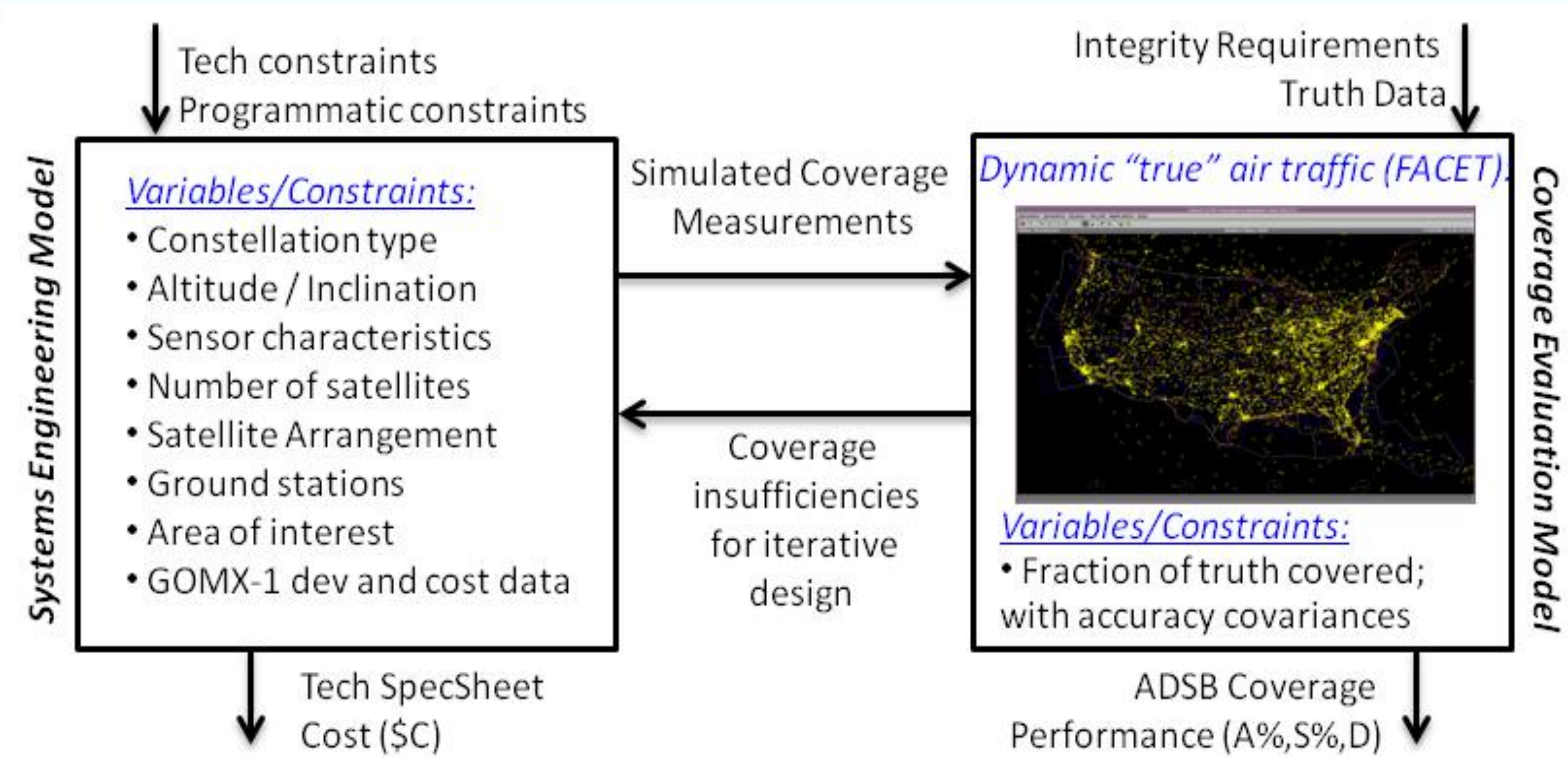
Attitude Determination and Control

- Nadir Pointing
- 5 degree attitude knowledge accuracy
- 10 degree attitude control accuracy

-Will need to develop a new antenna that covers more than 20 deg, or develop the ability to stick more antenna as payload

-May need reaction wheels for better attitude control

Constellation Design Method



-Constellation types: Walker-type, Ad-hoc, Precession-type

-Altitude: 500 km-600 km; Inclination: 80-90 deg; FOV: 131 deg

-Arrangement: Walker (1-3 planes, 9-27 sats), Precession (10-30 sats)

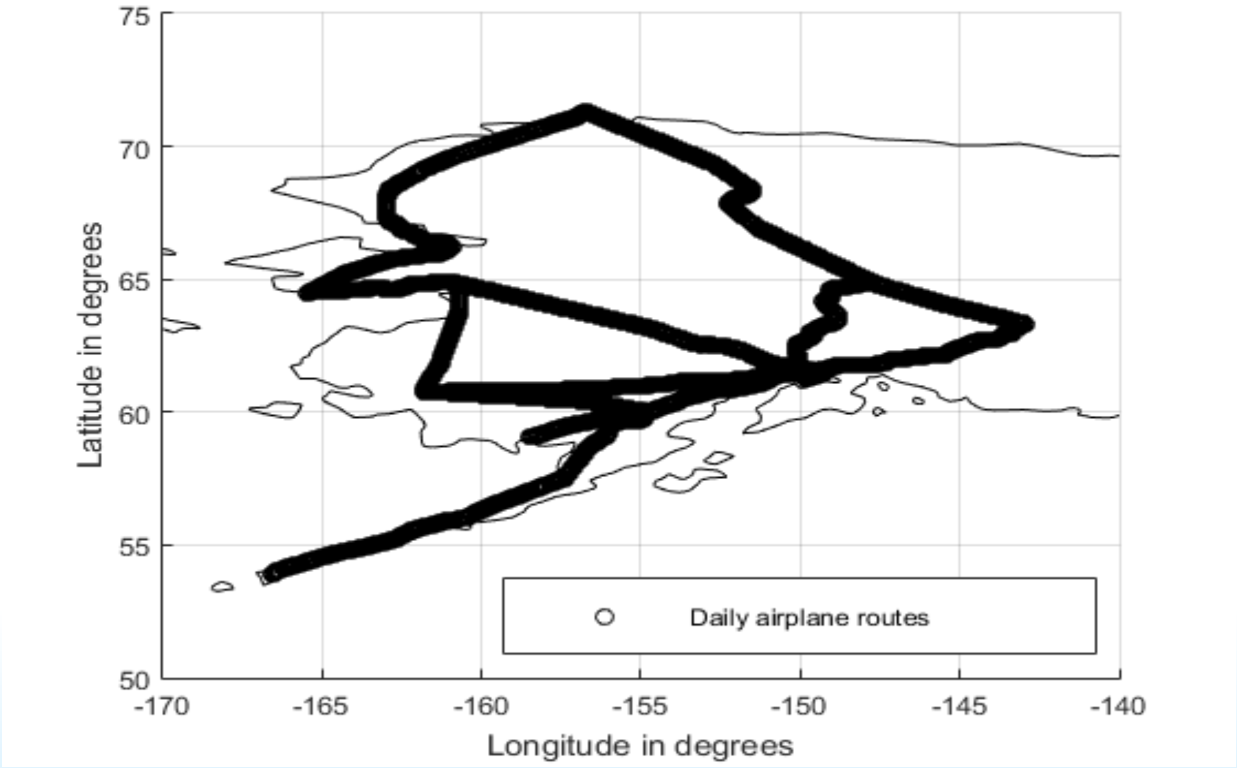
-Ground Stations: NASA Near Earth Network (12 stations available – govt and commercial)

-Area of Interest: Alaska

-Cost from GOMX: First unit at $350k, Learning curve at 93% + primary/secondary launch

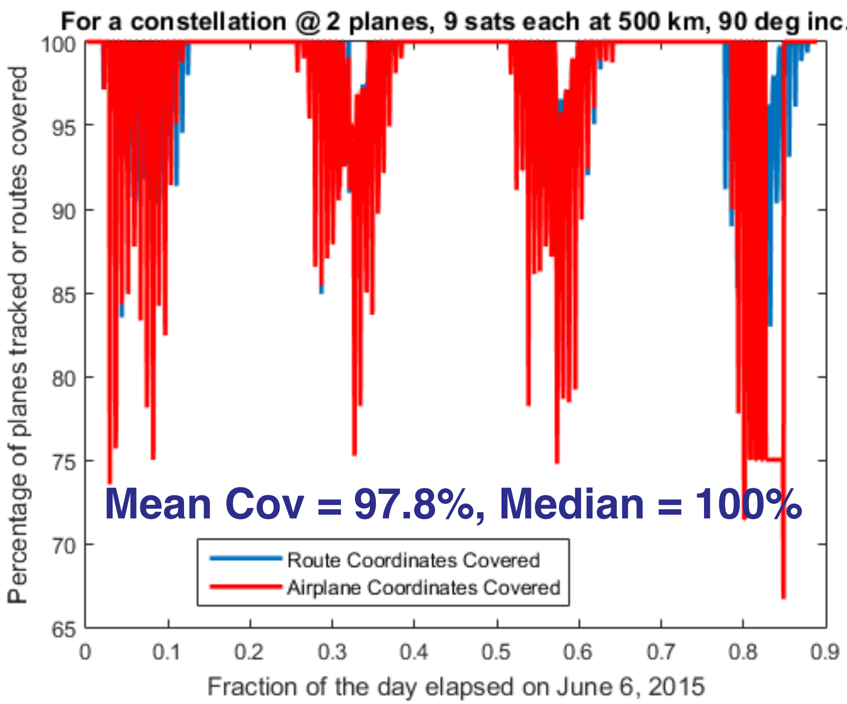
Airplane Population from FACET

- FACET = Future ATM (Air Traffic Management) Concepts Evaluation Tool
- 22 hours simulated on starting June 6, 2015 6 am UTC
- 22 possible flight paths between any 2 unique airports (15 total) in Alaska considered
- 30 flights for each flight path simulated at 1 minute intervals, and their lat/lon recorded
- This space-time database for airplanes is used as “reference” for tracking using a cubesat constellation



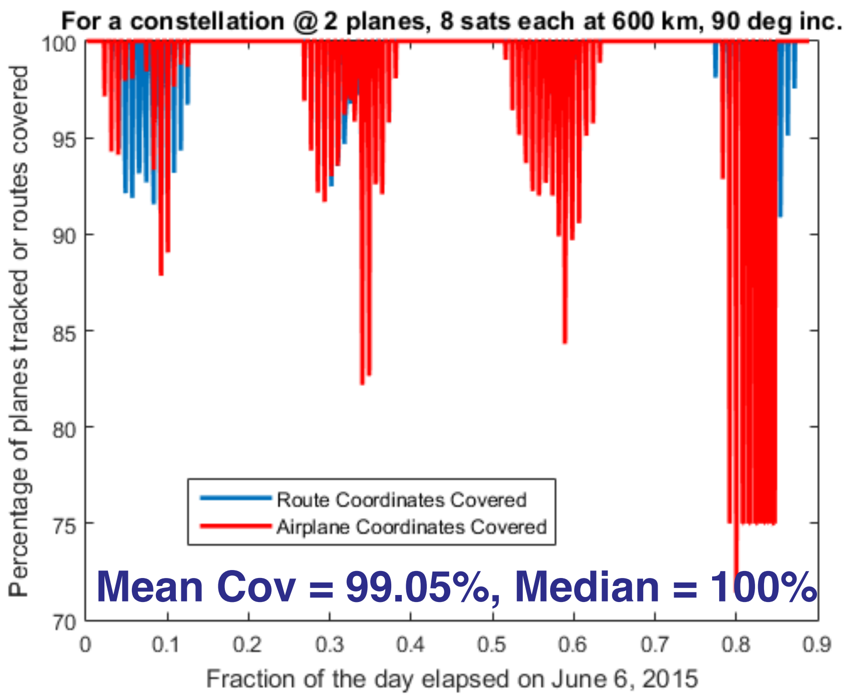
Performance of Walker Const.: % Instantaneous Coverage

18 sats in 2 planes at 500 km, 90 deg

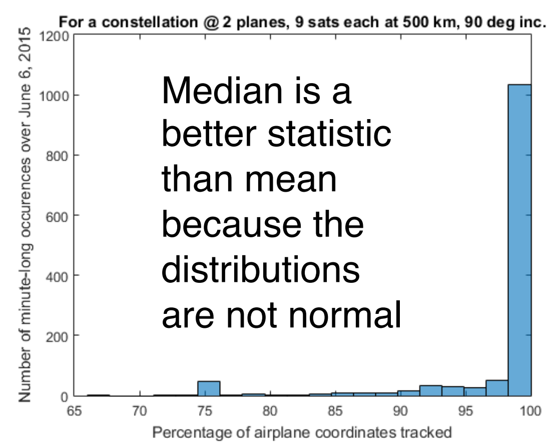


Mean Cov = 97.8%, Median = 100%

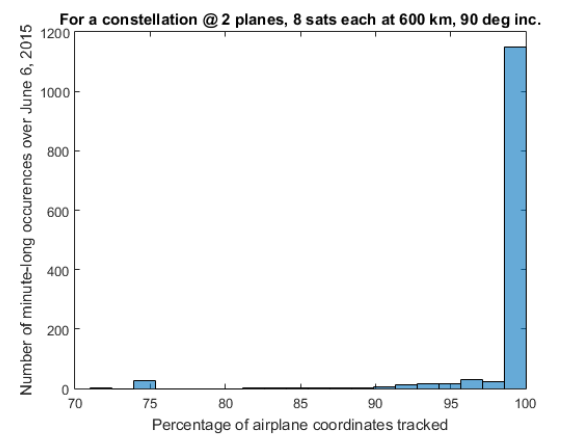
16 sats in 2 planes at 600 km, 90 deg



Mean Cov = 99.05%, Median = 100%



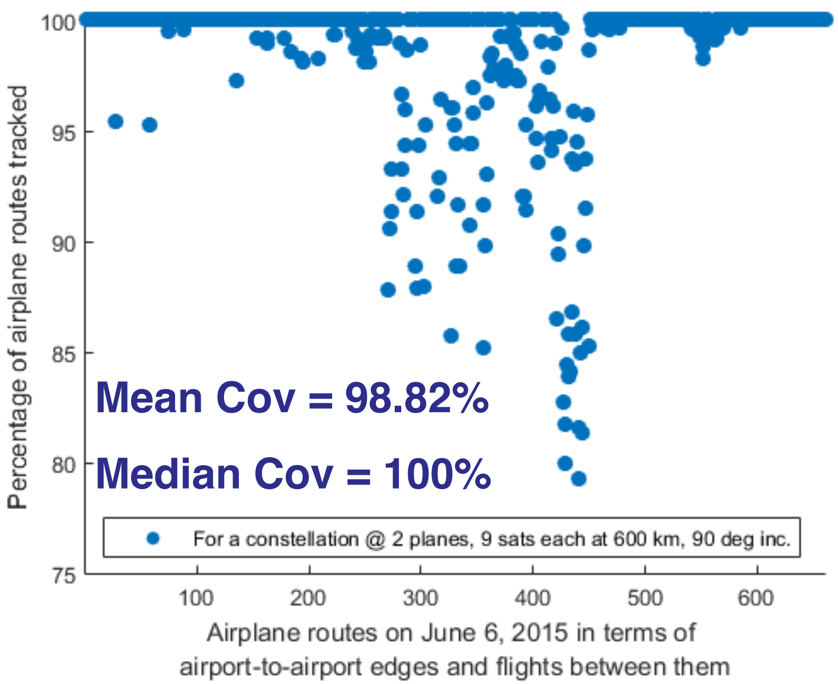
Median is a better statistic than mean because the distributions are not normal



27 sats in 3 planes provides 100% mean instantaneous coverage.

Performance of Walker Const.: % Route Coverage

18 sats in 2 planes at 500 km, 90 deg



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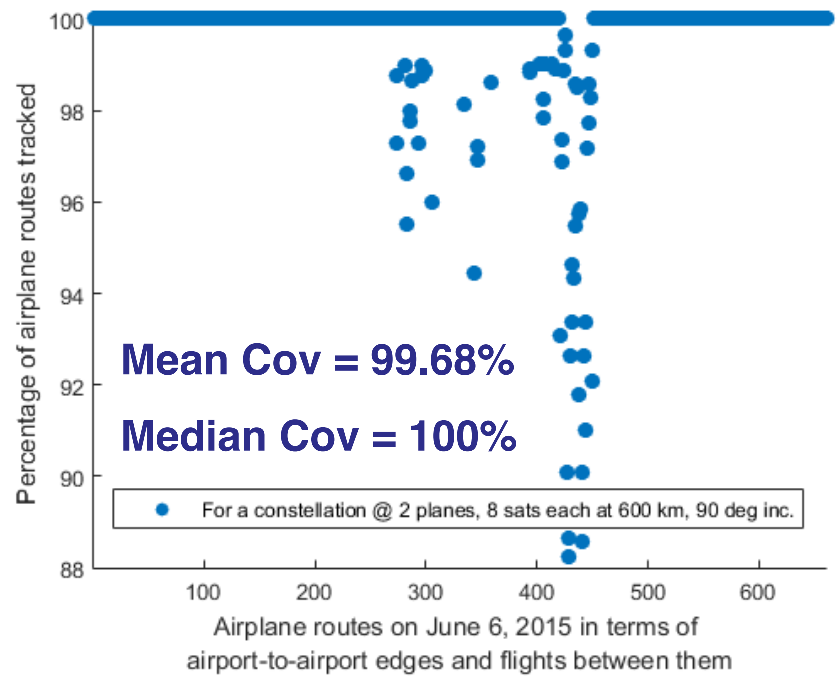

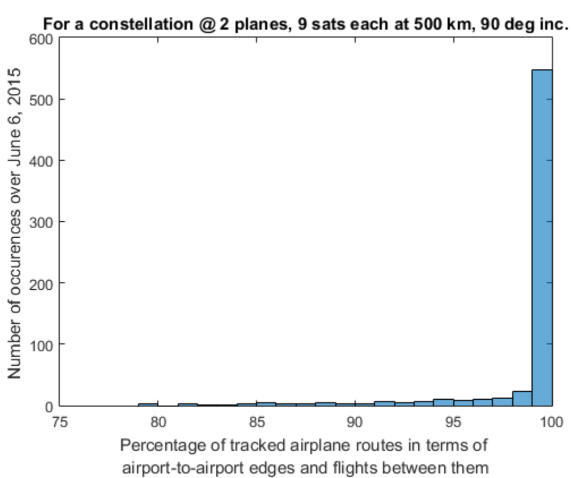

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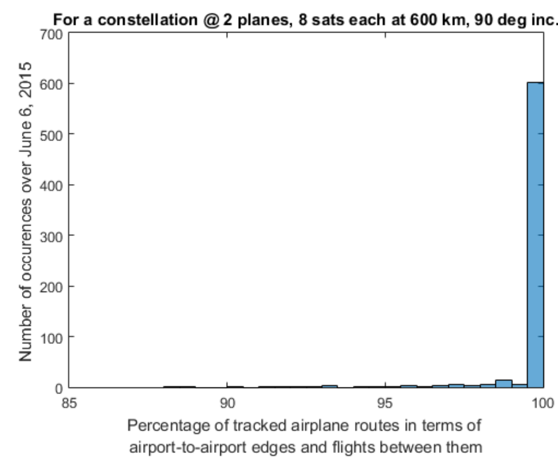
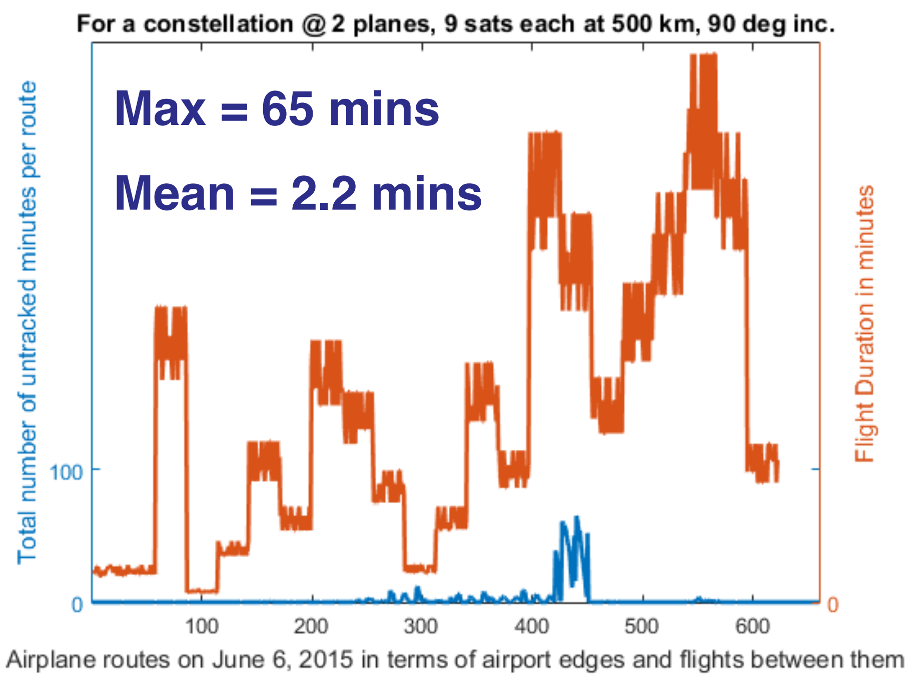
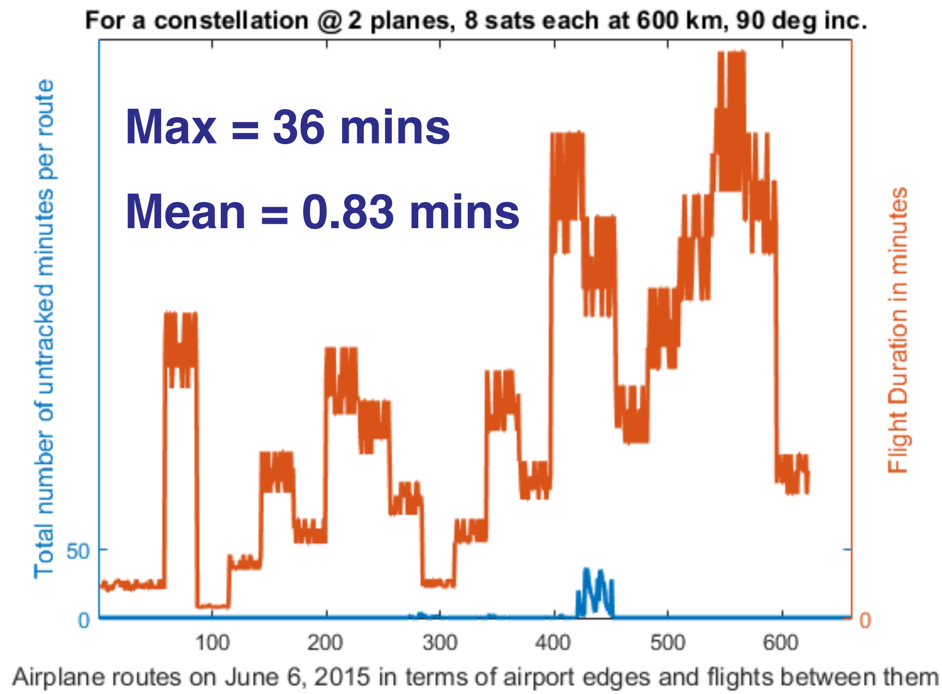


Performance of Walker Const.: Untracked Minutes

18 sats in 2 planes at 500 km, 90 deg



16 sats in 2 planes at 600 km, 90 deg



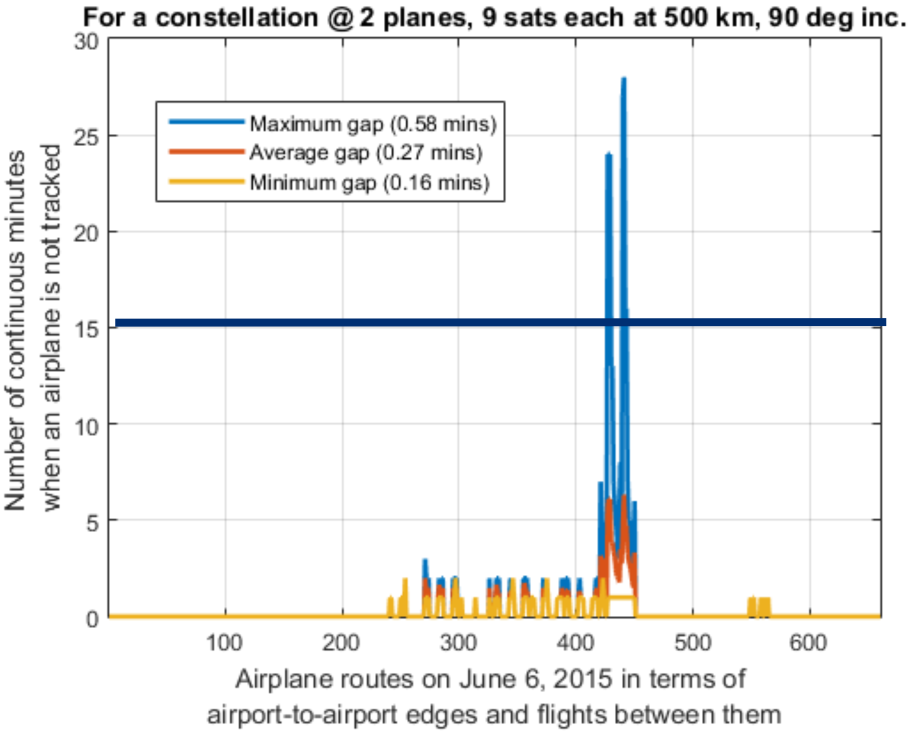
- ICAO has recently mandated that airplane states be tracked every (at least) 15 mins

- Lack of continuous tracking info is more important than the cumulative minutes then. Continuous gaps will be plotted on the next slide.

Approved for Public Release

Performance of Walker Const.: Transmission Delay

18 sats in 2 planes at 500 km, 90 deg



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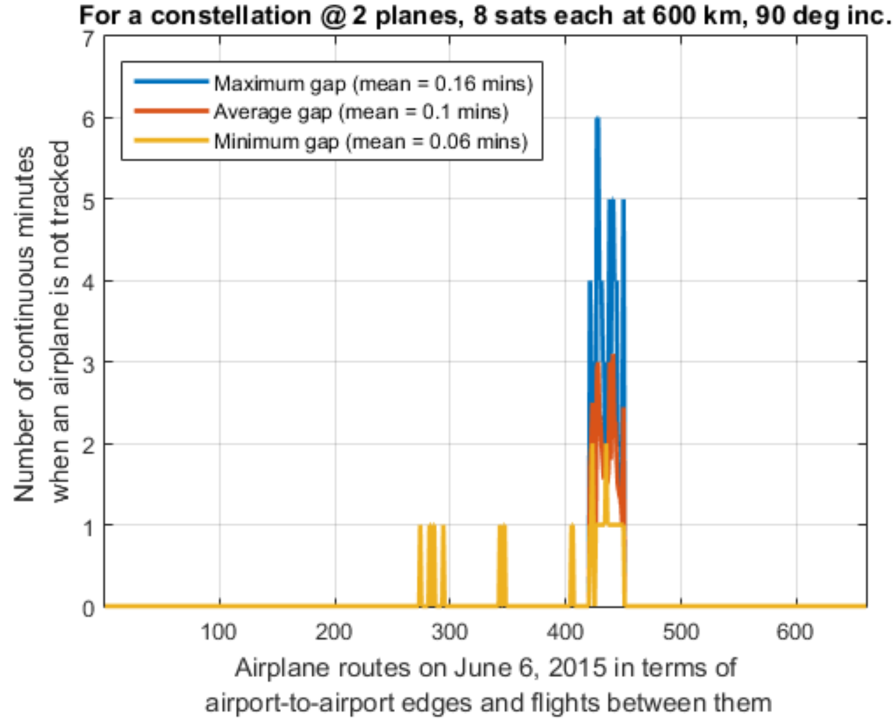


Only 7 of 660 flights exceeded the 15-min-not-tracked limit i.e. 1%

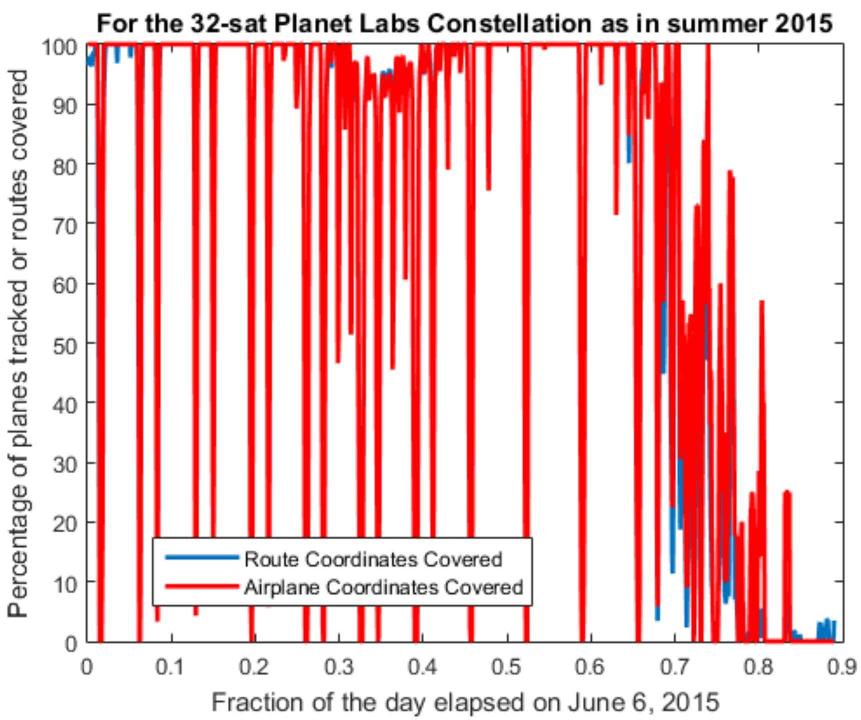
Average is under 30 seconds!

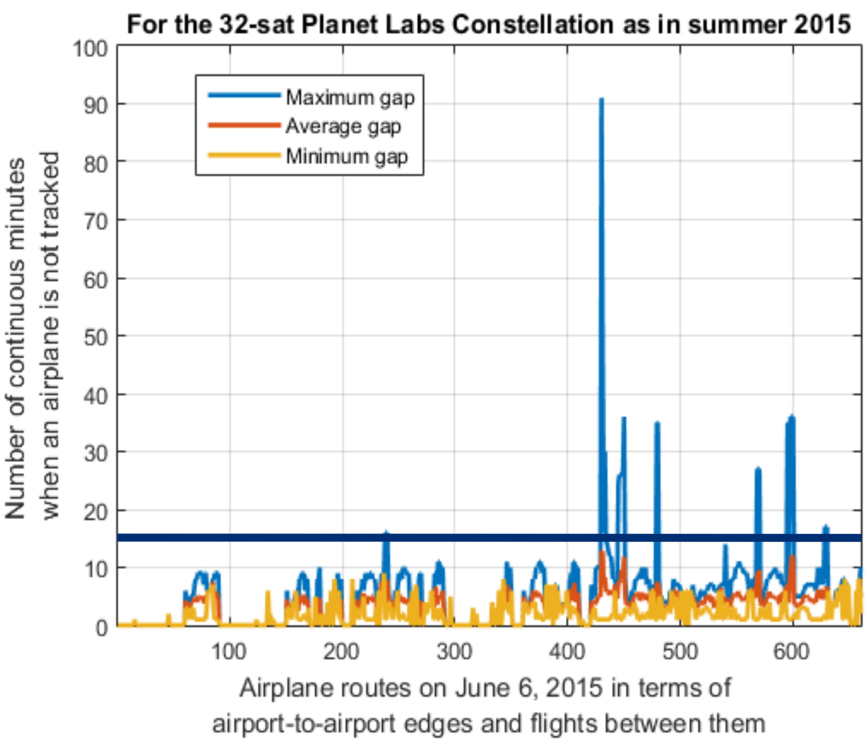
NONE of the 660 flights exceeded the 15-min-not-tracked limit

Average is under 6 seconds!

Performance of Ad-Hoc Constellations

32 current Planet Labs satellites in ISS and 606 km SSO orbits





Average Coverage = 74.7%

Tracking gap < 15 mins for 90% of routes BUT ~90 mins are unobserved for some routes.

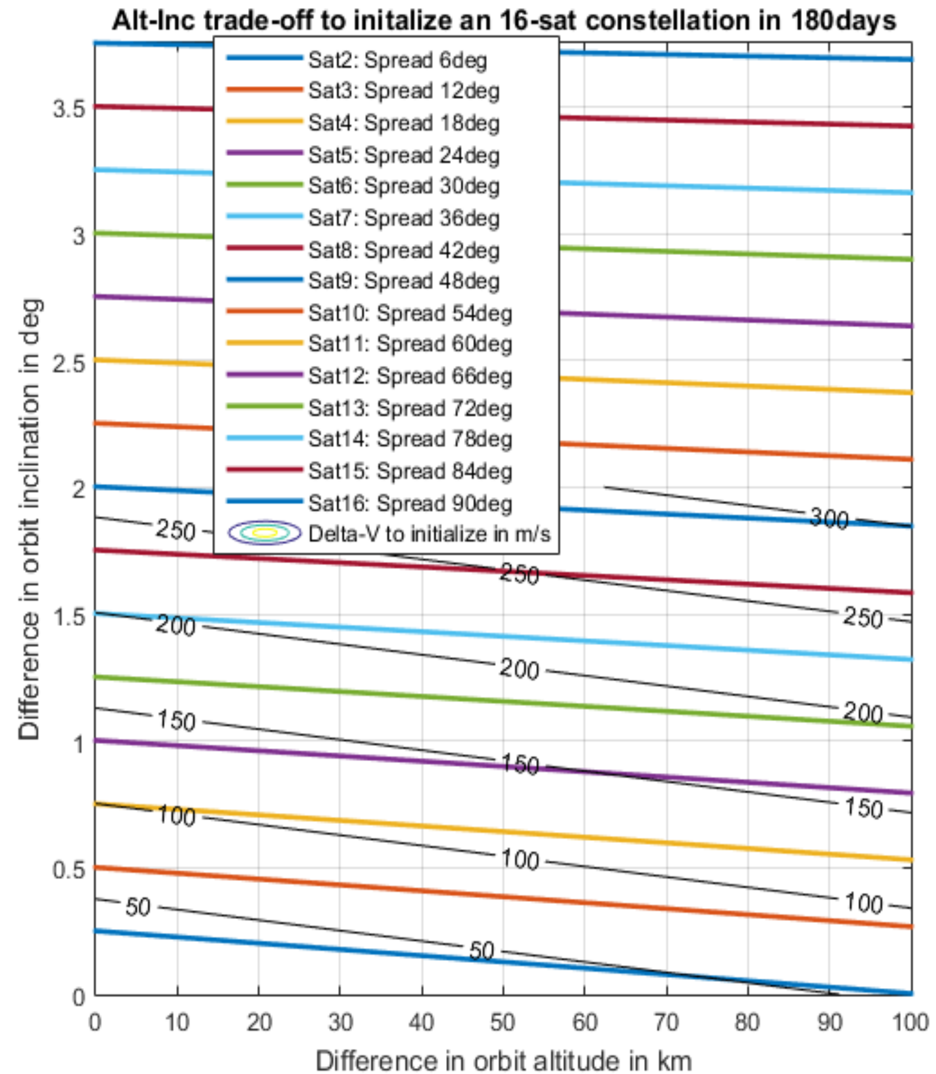
Since the Alaskan airspace ranges from 54° to 71latitude, the 51.6°Doves will cover very little of the airspace even with the 36 earth centric angle sensor, corresponding to limb-to-limb sensing at 320 km.

Continuously Precessing Constellation

RAAN spread obtained from differential altitude and inclination

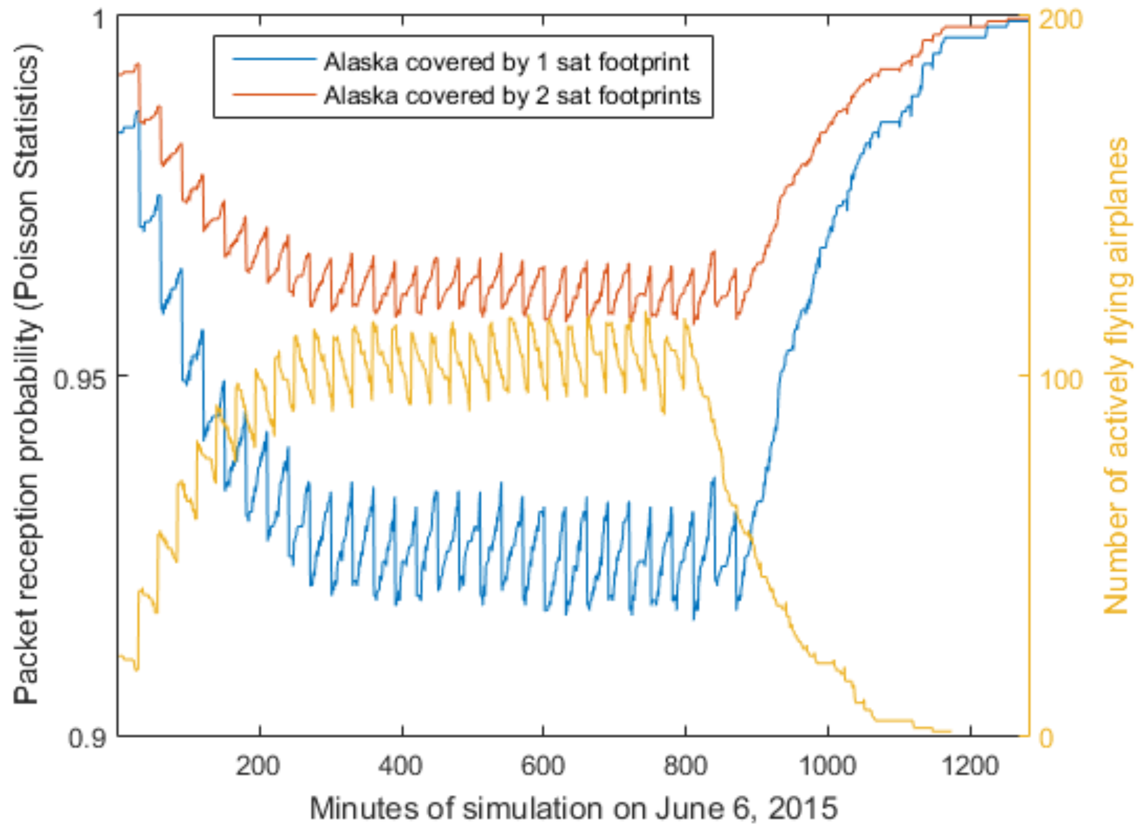
BUT same problem as the ad-hoc constellation i.e. the spread will not remain uniform without onboard propulsion

Moreover, not enough fuel is available in a small rocket such as the Pegasus to deploy satellites in less than 6 months. Larger rocket or upto one year of dispersion time will be needed.



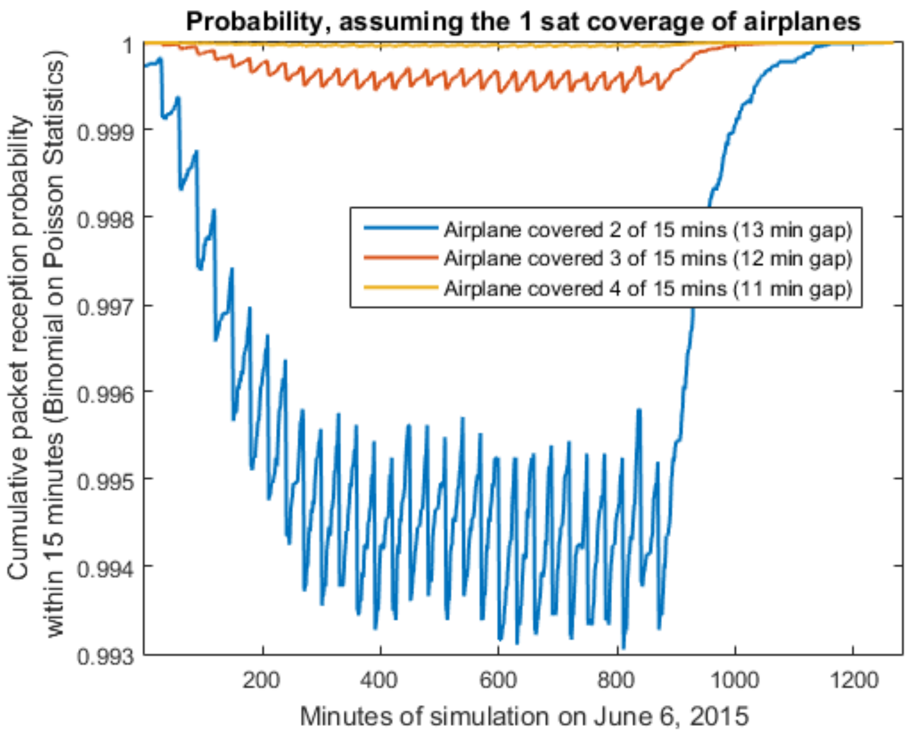
Performance: Packet Collision Probability

- When many airplanes are within the satellite FOV and packets delivered by any happen to reach the satellite at exactly the same time, some/all may get dropped.
- No physical model for simulating the packet drop rate yet.
- BUT, as a first cut, packet reception can be modeled as a Poisson process at the 3.1 messages/second/airplane rate and 120 us message length.
- Since a large FOV is assumed, the instantaneous airplane population can be viewed by 2 sats atmost. Without FOV overlap, there is no difference among architectures.



Performance: Packet Collision Probability

- Cumulative probability of dropped packets can be modeled via the binomial probability theorem. Probability of state reception within 15 mins > 0.99 even with an 13 min continuous gap and 1 packet/min.
- Realistically, 1 packet/second is transmitted.
- Maximum number of airplanes at any instant is 113 in the current simulation => maximum, instantaneous, collision probability of 0.9194. When the aircraft population is increased by 2-, 4-, 10- and 20-fold, prob => 0.85, 0.71, 0.43 and 0.19 respectively. Successful reception within Half minute at more than 99% probability, even if the air traffic is 20 times that of our FACET simulations
- That's an increase in probability of failure by an order of 30!!
- If transmission was per minute, An 11 minute gap => 55.55% at 20 times the air traffic
- More frequent transmission is needed to mitigate dropped packets



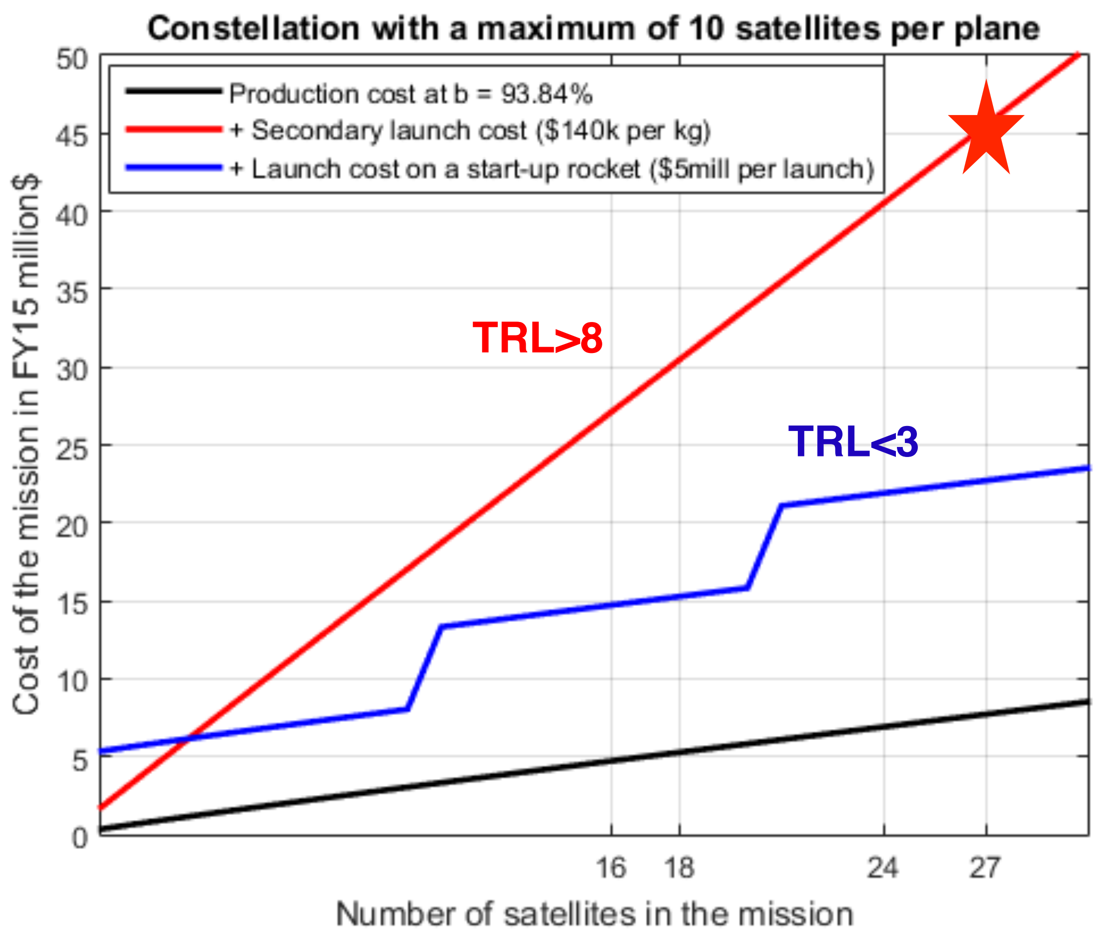
High-level Cost of architectures

- GomSpace Sales Team: "*250k USD for one fully flight ready ADS-B satellite coming down to 175k USD as the number of satellites approach 50.*"
- Learning curve should be steeper than quoted. Added $100k/sat for better ADCS/updates
- Launch costs depend on the launch option:

  - Primary launch with Pegasus for the Precession constellation can cost upto $40 mill and can carry 200 kg (30 7kg sats)

  - Primary launch with one of the startup companies can be as low as $5 mill/launch for 110 kg (15 7kg sats). Multiple launches needed for the Walker constellation.

  - Secondary launch with a provider like SLS can cost upto $140k per kg on e.g. Falcon9. Multiple launches needed for the Walker constellation.



Future Work

• Antenna development in keeping with Thales Alenia's large FOV antenna for the Iridium constellation

• Extend the tool to unmanned air traffic tracking. Add Alaska elevation mask for impact calculation due to possible loss of line of sight

• Better model development for packet collision and satellite-aircraft communication in general

• Address the security and jamming concerns of ADS-B. ADS-C could be an option.

• Planning and scheduling activities for large numbers of spacecraft interacting with large numbers of airplanes and large numbers of ground stations

•Make the tool available for release so that anyone can use it to design constellations for aircraft tracking for any airspace and satellite capability

Questions?

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CubeSat Constellation Design for Air Traffic Monitoring

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STATUS QUO

Lack of dynamic air traffic control in remote locations hinders

Problem: Global and local air traffic can be tracked and controlled by receiving the Automatic Dependent Surveillance-Broadcast (ADS-B) signal. Lack of real-time aircraft time/location information hinders optimal planning and prevents search-and-rescue.

Current solution: Terrestrial receivers track planes but not over remote oceans and sparsely populated areas.

Proposed solution: Perform simulations and propose a constellation of cubesats in low Earth orbit that will receive ADS-B signals from aircraft and relay them to ground stations.

NEW INSIGHTS

FAA mandates aircraft in Class A, B, C, and E airspace to be ADS-B equipped by 2020. The 2U GOMX-1 with ADS-B receiver showed success. Continuous, remote access needs constellations.

Proposing optimal constellations using the 2U cubesat as first unit will reduce inter-airplane spacing, fuel consumption, flight time. Predictions show16-fold increase in trans-oceanic flights.

We'll provide tightly coupled traffic simulations and constellation design.

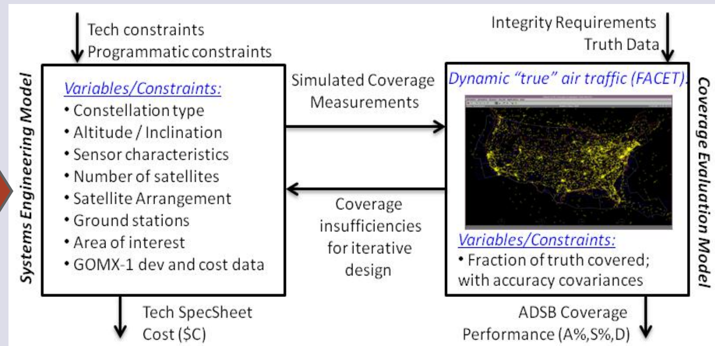
ACHIEVEMENT

MAIN ACHIEVEMENT:

Build a software tool for designing a constellation of cube-sats for space-based ADS-B monitoring of aircraft in remote locations. The tool will tightly couple high fidelity air traffic simulations using FACET with constellation architecture enumeration on STK and evaluation/selection on MATLAB. The output trades will allow an optimal design selection.

HOW IT WORKS:

Many architectures are generated (STK, MATLAB) using variables on the left and evaluated on the right using "true" air traffic data (FACET).



ASSUMPTIONS AND LIMITATIONS:

No reliable model currently exists on data integrity or comm quality of aircraft ADS-B signals to spacecraft range, as received in thousands per cubesat per second. Flight results from GOMX-1 will be assumed as state-of-art, more theory dev required.

QUANTITATIVE IMPACT

Potential customers and Applications:

General Aviation pilots

Air Traffic Control for oceanic operations

Flight Service Stations

Quantitative metrics:

Our tool will provide trades between performance (A% area covered at C% certainty of aircraft states with delay D) and cost ($C) for dozens of architectures generated from many variable combinations. Alaska and Pacific will be use cases for locations (otherwise variable). Performance-cost efficiency will be compared to that expected from an ADS-B equipped Iridium Constellation.

END-OF-TASK OBJECTIVES

Deliverables: Software tool + design recommendations for Alaska/Pacific

Start-end TRL: 2 to 3

Team:

Joseph Rios/ARC-AFO: Air traffic sims

Sreeja Nag/BAERI: Constellation tool

GomSpace ApS: GOMX-1 flight data

Follow-on work:

Develop a constellation of ADS-B cubesats with proposed designs and GOMX-1 cubesat prototype.

We will build a tool for designing a constellation of small satellites based on real-world air traffic data to demonstrate the value of space-based ADS-B tracking, through high-fidelity simulation and modeling, leading to recommendations for cost-efficient deployment to increase situational awareness in poorly-served surveillance areas