



Small Satellite Operator Best Practices for SSA and Conjunction Assessment

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AGENDA

- Introduction to Planet
- Orbit Determination
- Conjunction Assessment and Response



OUR CONSTELLATIONS

CONSTELLATION	DOVE	RAPIDEYE
Constellation	120+*	5
Image capture capacity	150 million km ² /day	6 million km ² /day
Ground Sampling Distance (GSD)	3-5 m	6.5 m
Pixel Resampled	3.125 m	5 m
Telescope and Camera	Bayer mask CCD sensor	Push broom imager
Spectral Bands	Red, Green, Blue and NIR	Red, Green, Blue, Red Edge and NIR

* Estimated number of Dove satellites to achieve a daily revisit rate - target delivery end of 2016

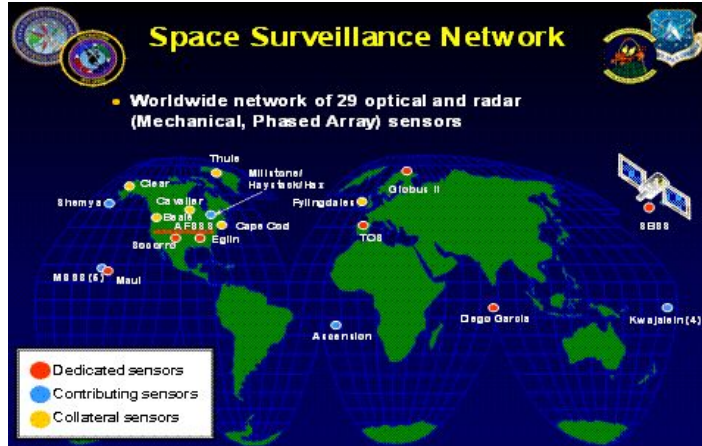




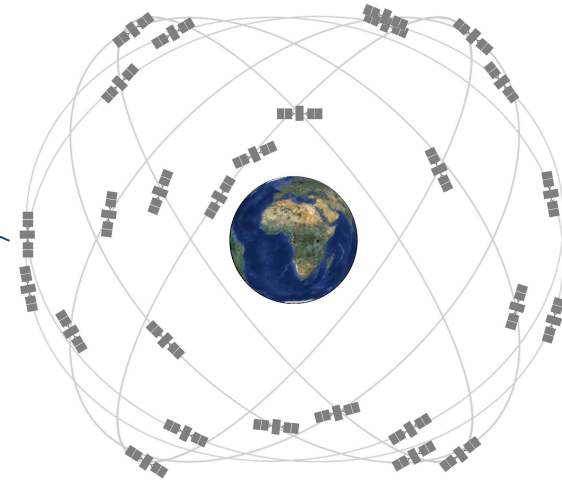
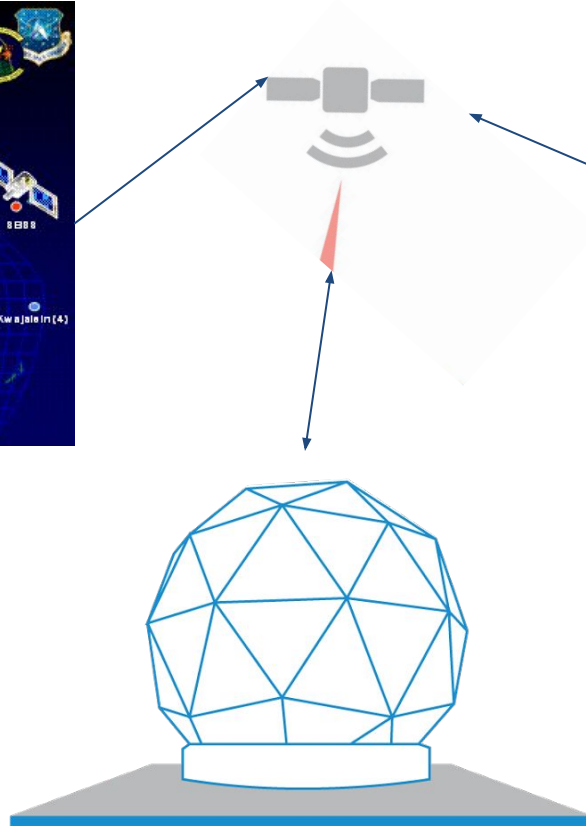
Orbit Determination

Muir Woods & Mt. Tamalpais, California, USA DEC 23, 2015

Measurements



[www.stratcom.mil]

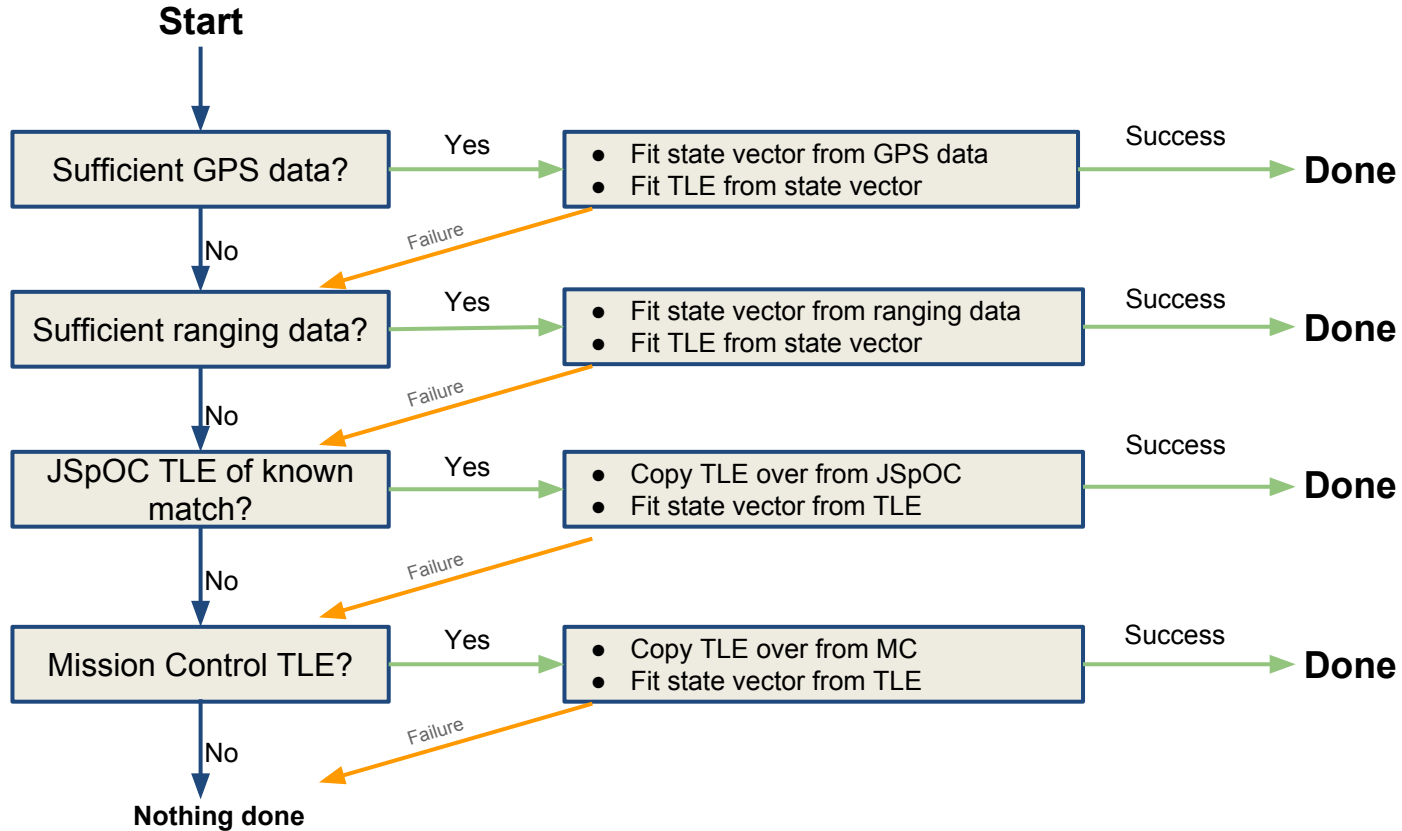


[www.gps.gov]

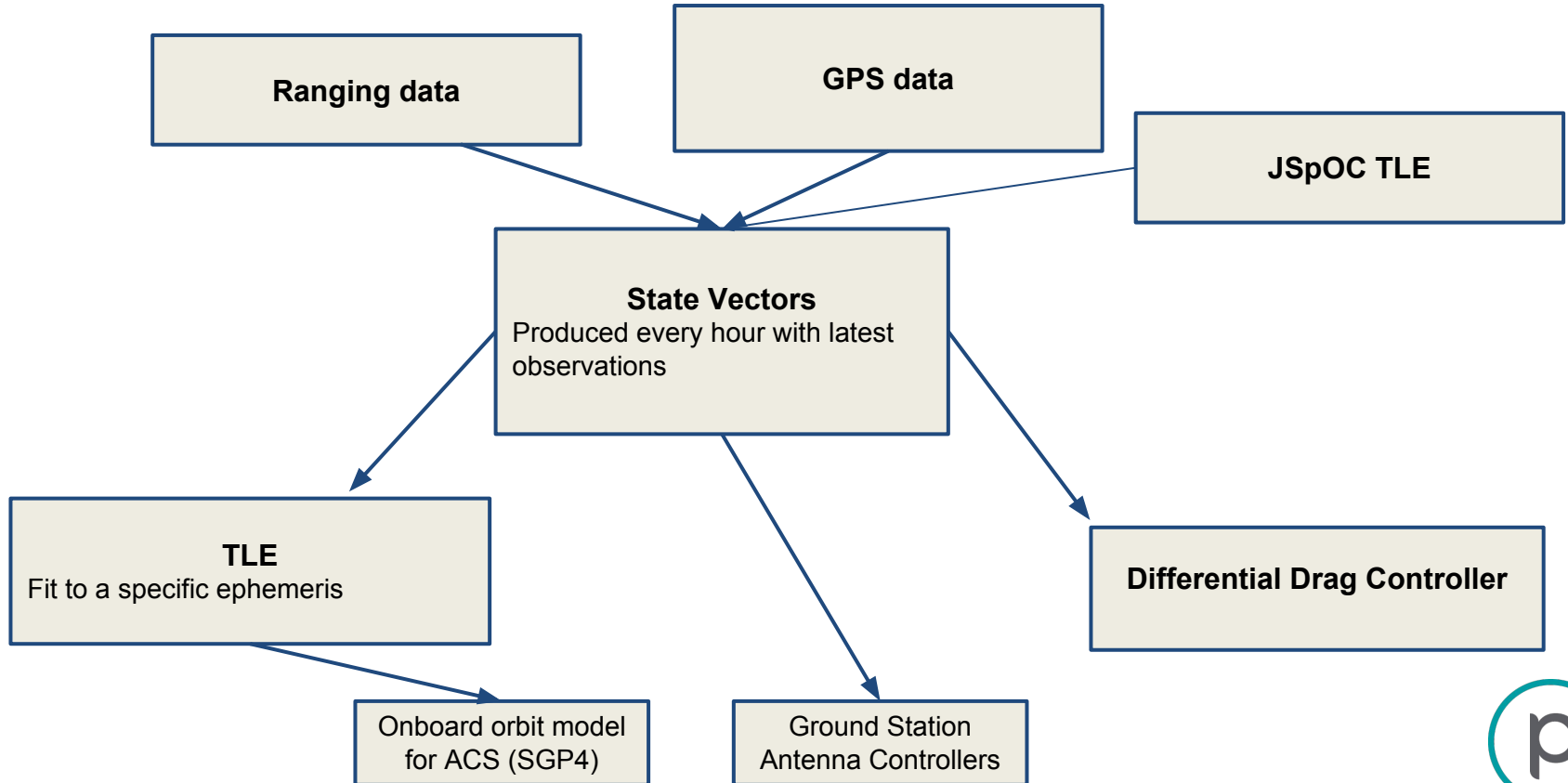
Antenna Map



Orbit Fitting Logic



Flow of Information





Conjunction Assessment and Response





Philosophy

- Responsible space neighbor
- Open and transparent about operational policies and orbit data
 - Orbital Ephemerides publicly available at <http://ephemerides.planet-labs.com/>
 - Orbital Ephemerides sent to the Space Data Association (SDA)
 - Communicate regularly with JSpOC
 - Collaborative
- Automation
 - Mission Control team of just a handful of people manages the entire fleet of satellites





Responsible Space Neighbor

- Compliance with the 25 year rule
 - Strive for less than 10 years (related to operational lifetime)
- Adopt NASA Procedural Requirements for Limiting Orbital Debris [NASA-STD 8719.14]
- Ideal altitude of 475-580 km
 - Orbital life < 10 years
 - Choice limited only by access to launches as secondary
- Continuous orbit determination and conjunction assessment





Responsible Space Neighbor

- 78 % of satellites have a lifetime < 5 years
- 94 % of satellites have a lifetime < 10 years
- 95 % of satellites have a lifetime < 15 years
- 98 % of satellites have a lifetime < 20 years
- 100 % of satellite have a lifetime < 25 years





Methods

- Combination of thorough analysis and expertise
- Team has experience in academia and at NASA working on the conjunction assessment problem from multiple angles
- Experience with operations at NASA and other commercial space companies
- Prepared to collaborate and cooperate





Open and Transparent

PLANET LABS PUBLIC ORBITAL EPHEMERIDES

Orbits derived from 2-way UHF ranging data and are typically accurate to better than 2 km within 24 hours of epoch.

Latest TLEs: http://ephemerides.planet-labs.com/planet_mc.tle
Historical TLEs: http://ephemerides.planet-labs.com/planet_mc_YYYYMMDD.tle
Latest state vectors: <http://ephemerides.planet-labs.com/planet.states>
Historical state vectors: http://ephemerides.planet-labs.com/planet_YYYYMMDD.states
State vector file format:
Col1: Hardware ID (satellite serial number)
Col2: Epoch in [s] since J2000 epoch Terrestrial Time
Col3,4,5: Position in J2000 frame [m]
Col6,7,8: Velocity in J2000 frame [m/s]
Col9: Drag Ballistic coefficient in [kg/m2]
Col10: SRP ballistic coefficient in [kg/m2] (not currently fit)

JSPOC MATCHING REPORT

Due to cross-tagging, the mapping between JSPOC catalog ID and satellite is not always constant. This report gives the current best-match JSPOC catalog ID to each Planet Labs satellite, along with a measure of the quality of the JSPOC orbit. The list may not be complete if one or more satellites have no matching orbits on JSPOC at the moment.

http://ephemerides.planet-labs.com/js poc_matches.txt

The following satellites are still in orbit but retired; orbit information may be obtained from Space Track:

Dove 2 has NORAD Catalog ID 39132

Dove 4 was never released from UniSat-5; NORAD CatID 39434 is *not* Dove 4.

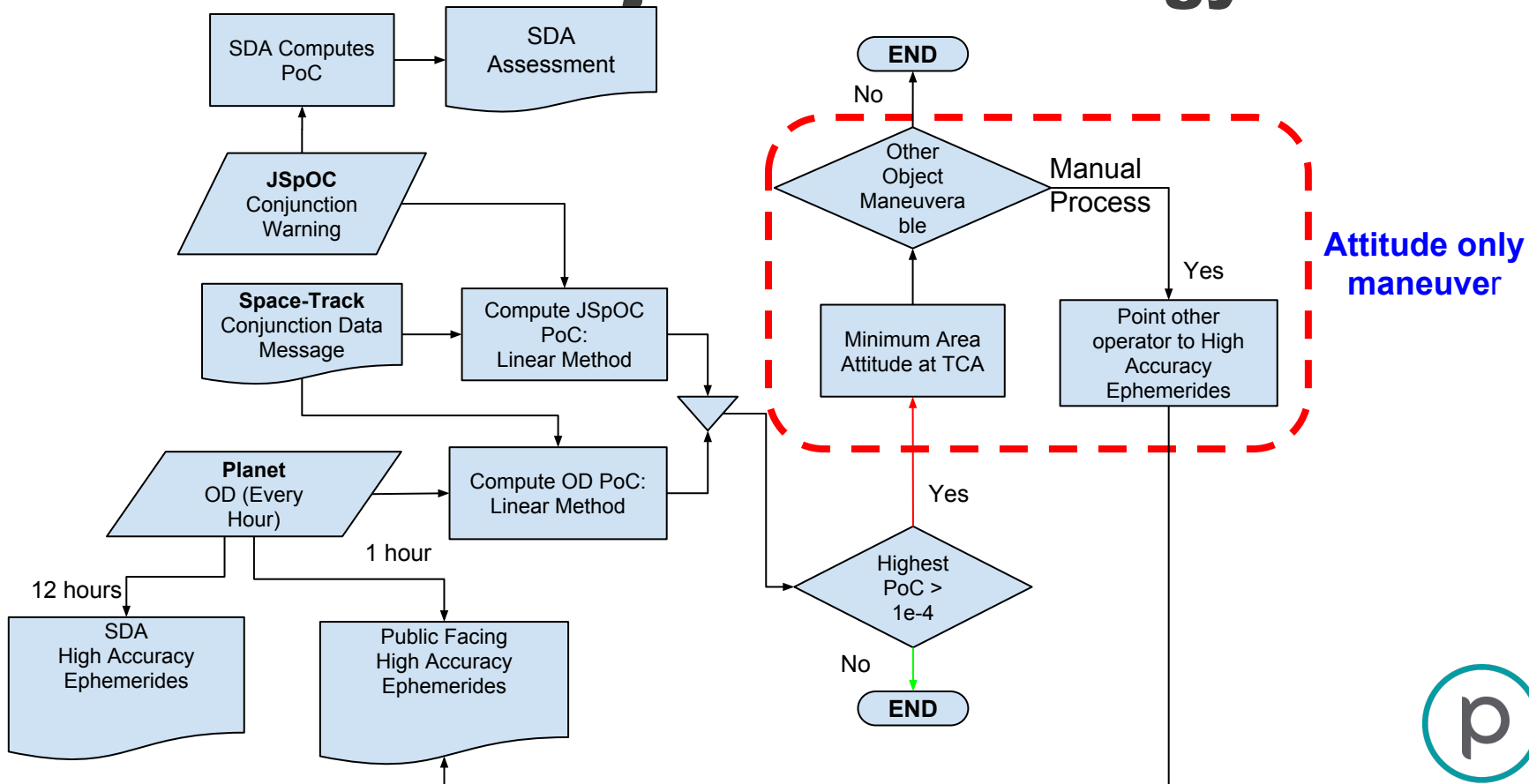
For technical or operational questions, or to request permission to redistribute these data or use in a publication, email orbital-neighbors@planet.com

0C07	FLOCK 1E 13	40740 (3.9)	FLOCK 1E 13
0C13	FLOCK 2E 11	41574 (1.1)	FLOCK 2E 11
0C14	FLOCK 2E 9	41571 (1.9)	FLOCK 2E 9

41570 (30.2) FLOCK 2EP 7 [MISLABEL]



Current Conjunction Strategy



Conjunction Warnings

```
# JSpOC Conjunction Report, with Planet Labs re-assessments
# Epoch: 2016-08-08 13:00:01.000 UTC

# 0 new JSpOC conjunction(s) [Highest PoC = 3.151e-10]

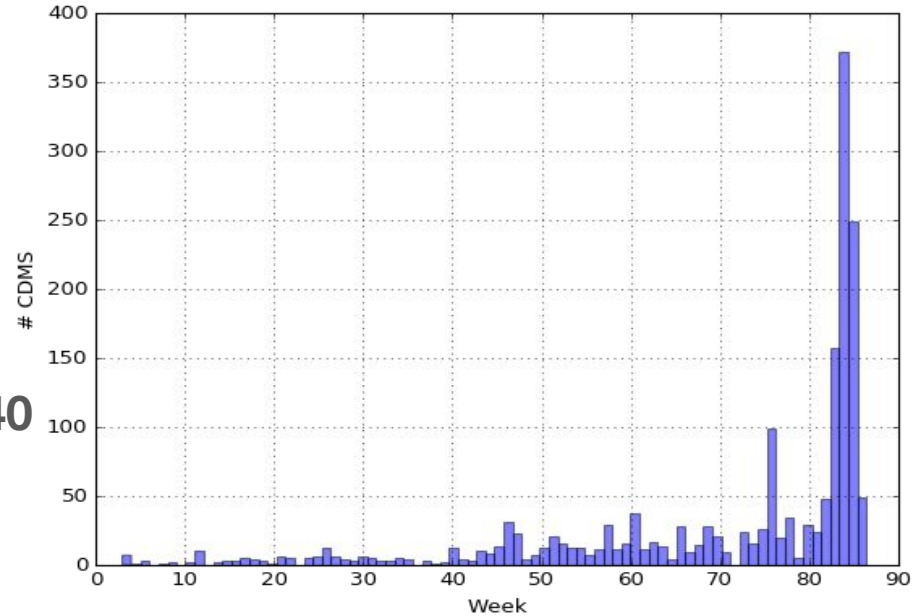
# Summary (legend at bottom of report)
# T-      CDM ID      CATIDs      HWIDs      dR      dR_fpp      covs      PoC      PoC_fpp
# hrs      1-2      1-2      km      km      km      km
+54.05  5306399  41566-41486 0C2B-0C60  0.568  8.093 10.627  0.000e+00  0.000e+00
+53.54  5306400  41575-41479 0C19-0D05  0.995  1.583  9.474  0.000e+00  0.000e+00
+40.79  5295832  40036-28855 0908-0000  0.652  3.868  0.827  2.311e-11  4.723e-27
+28.00  5298771  41577-39165 0C27-0000  0.604  1.558  5.691  3.151e-10  3.189e-12
+11.37  5303145  41577-41486 0C27-0C60  0.467  1.300  1.792  0.000e+00  0.000e+00
+2.34   5292156  40026-32157 0909-0000  0.523  0.652  0.648  2.793e-10  0.000e+00
-40.24  5288166  41483-41571 0C37-0C14  0.583  0.655  0.647  0.000e+00  0.000e+00

# CDM 5306399 @ TCA = 2016-08-10 19:02:44.101 UTC (upcoming 54.05 hrs)
# CDM generated at 2016-08-08 11:56:07.000 UTC
# Obj1:      FLOCK 2E 8 (41566 == 0C2B) RCS = 0.0640 m2
# Obj2:      FLOCK 2E 3 (41486 == 0C60) RCS = 0.1130 m2
# Rel speed: 0.002 km/s, V1-V2 angle = 0.0 degs
#      dr (km)      covs (km)      PoC      PoC_max      dt_ca (s)
# JSpOC:  0.568 (6.186, 4.441) 0.000e+00  5.503e-05  -0.000135
# FPP:    8.093 (6.186, 4.441) 0.000e+00  2.579e-07  -85.286259
# Attitude maneuver at TCA: PoC = 0.000e+00 -> 0.000e+00 (max->min area)
# 0C2B (41566) FPP's RV_ECEF @ JSpOC's TCA:
# Rx = -1476.803279 km
# Ry = 5790.977760 km
# Rz = -3199.327035 km
# Vx = -4.172470478 km/s
# Vy = -3.712359413 km/s
# Vz = -4.802397563 km/s
# 0C60 (41486) FPP's RV_ECEF @ JSpOC's TCA:
# Rx = -1481.924949 km
# Ry = 5786.769760 km
# Rz = -3204.057340 km
# Vx = -4.170824199 km/s
# Vy = -3.721512699 km/s
# Vz = -4.798078862 km/s
# Obj1: FLOCK 2E 8
# 1 41566U 98067JQ 16221.21452296 .00016725 00000+0 22925-3 0 01
# 2 41566 051.6422 157.5070 0003669 050.4004 095.9227 15.57493559 03
# Obj2: FLOCK 2E 3
# 1 41486U 98067JG 16221.14284431 .00011207 00000+0 15797-3 0 07
# 2 41486 051.6428 157.8618 0001831 019.4886 088.2067 15.57141500 06
```



Conjunction Stats

- Range: January 2015 - July 2016
- Number of CDMS: ~1700
- Intra-Planet CDMS: ~ 850 (~50%)
- Unique non-Planet conjunctions ~ **240**



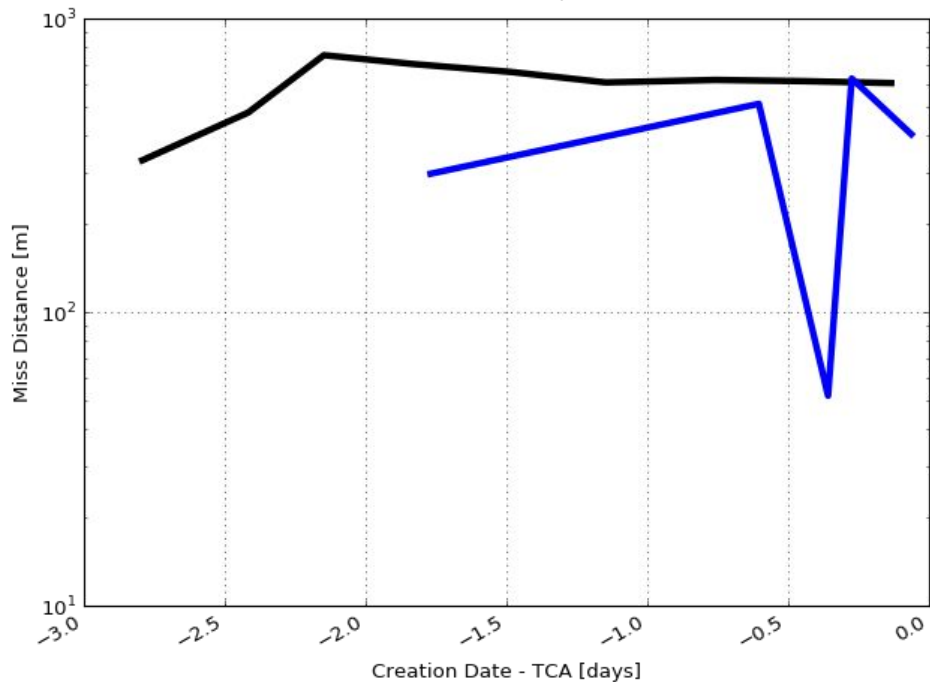
Conjunctions so far

- Any future conjunction with a PoC $> 1E-5$ is flagged and closely monitored
- Last attitude maneuver was end of March 2016
 - Flock 1C satellite and a rocket body
- Last monitored conjunction occurred mid-July 2016 (No action required)
 - Flock 1C satellite and another CubeSat



Conjunctions so far

Rocket Body

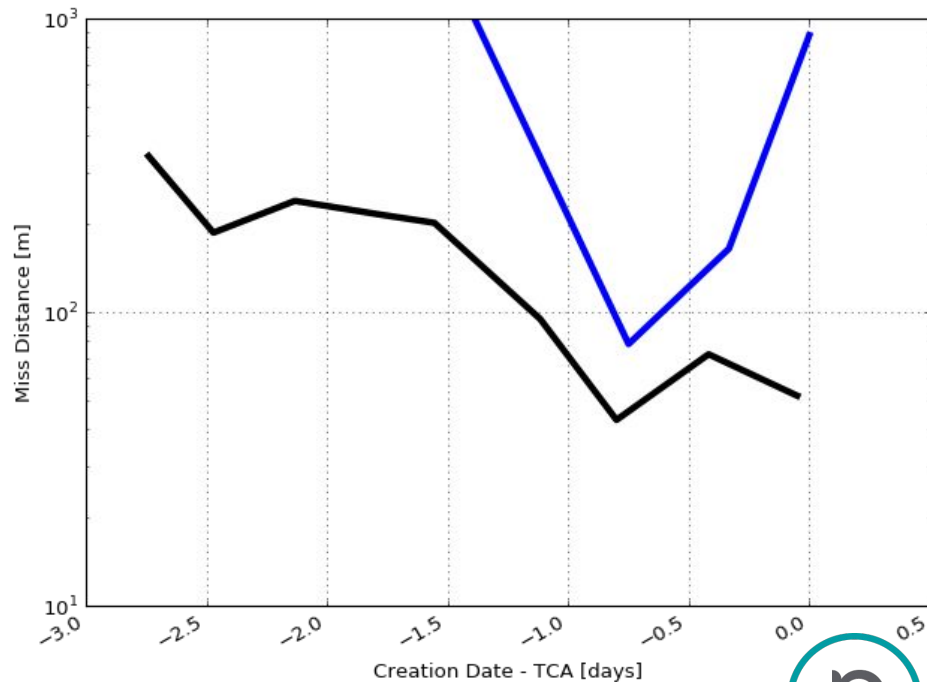


9 CDMS

Min separation: 330 m, 52 m

Planet
Ephemeris

Cubesat



9 CDMS

Min separation: 43 m, 78 m

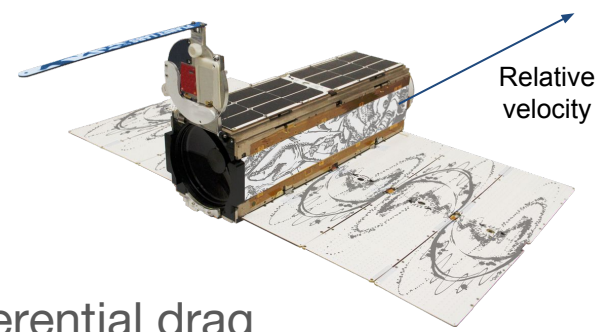


Proposed Conjunction Strategy

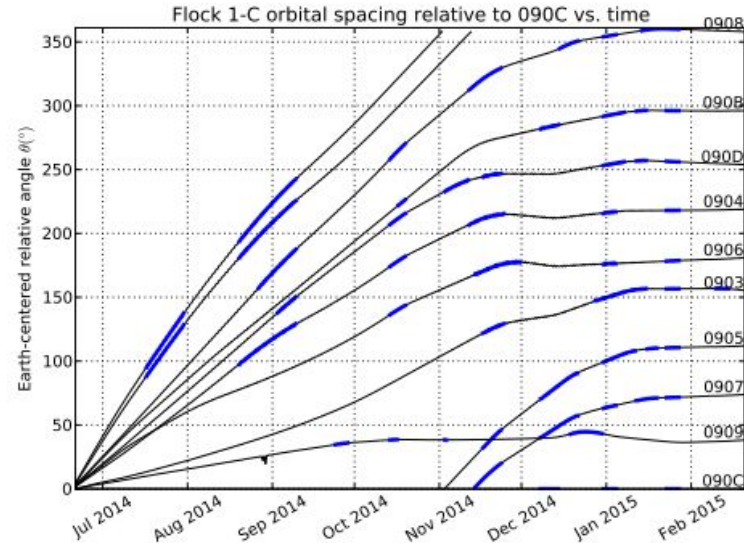
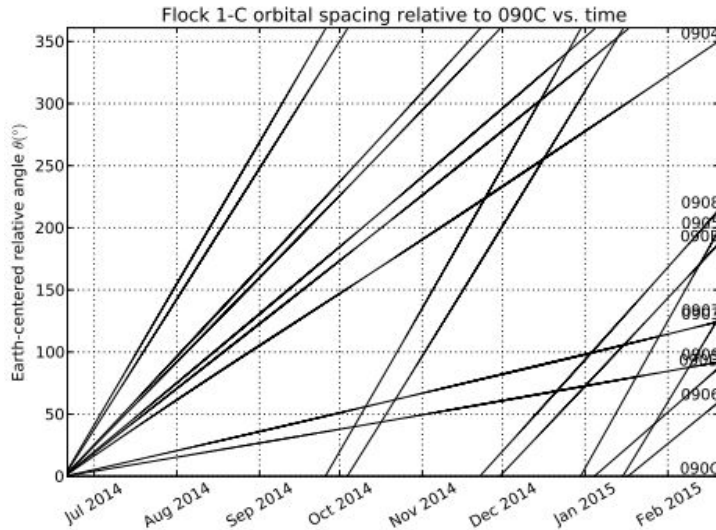
- Use Conjunction Data Messages from JSpOC and the SDA
- Use Planet ephemerides to compute Collision probability
- Only plan a maneuver if other object does not have propulsion
 - Use JSpOC and SDA to screen planned maneuvers



Avoidance Maneuver



- Consists of minimum attitude maneuver and differential drag
- Differential drag has been successfully used to spread Doves
 - $> 50 \text{ km/day}^2$ for sub-ISS 400 km orbit
 - $\sim 1 \text{ km/day}^2$ for 600 km SSO orbit





Exciting Future

Anticipating new SSA technologies such as the space fence and the commercial space catalog





THANK YOU

VISIT US AT PLANET.COM



London Array Wind Farm, United Kingdom, APR 17, 2016



APPENDIX SLIDES

Muir Woods & Mt. Tamalpais, California, USA DEC 23, 2015

An aerial photograph showing a coastal area with mountains on the left and a city on the right. The mountains are covered in dense green forest, with some brownish patches indicating cleared land or erosion. The city is built on a hillside, with a grid of streets and various buildings. A body of water is visible in the bottom left corner, with a sandy beach and a pier. The text "OUR APPROACH" is overlaid in the center of the image.

OUR APPROACH

A large, semi-transparent logo consisting of a stylized lowercase letter 'p' inside a circle, located in the bottom left corner of the image.

Muir Woods & Mt. Tamalpais, California, USA DEC 23, 2015

HISTORICAL APPROACH

- Tasking
- Low coverage
- Weeks to gain access
- Expensive



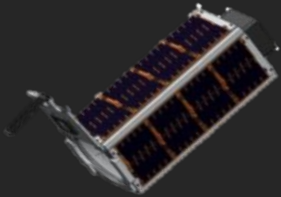
PLANET APPROACH

- Monitoring
- Global coverage
- Daily online delivery
- Affordable

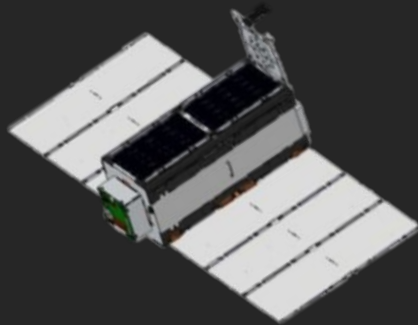


AGILE AEROSPACE

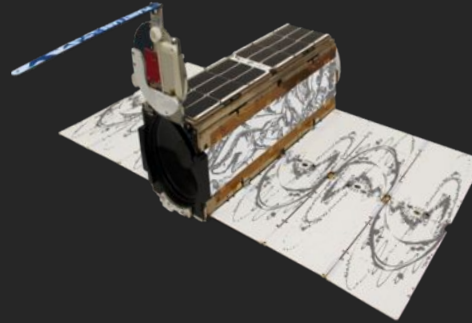
BUILD 1
APR 2012



BUILD 6
APR 2013



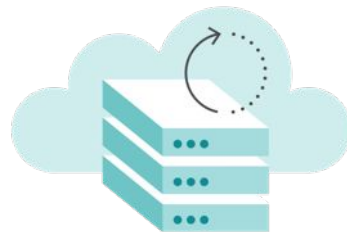
BUILD 13
JUN 2015



13 Builds in only 3 years



Mission 1 End-To-End System



100+

SATELLITES

3-5M

**RESOLUTION 4
BAND IMAGERY**

26

GROUND STATIONS

9

SITES

150+M

KM² PER DAY

1000s

**OF VIRTUAL
MACHINES**

5+TB

**DOWNLINKED
DAILY**

API

**FOR DATA PIPELINE
AND PLATFORM
ACCESS**

SAN GABRIEL WILDFIRES

SAN GABRIEL MOUNTAINS

JUNE 4, 2016

VEGETATION

bare

sparse

moderate

dense

SAN GABRIEL WILDFIRES

FIRE RETARDENT LINES
ARE IN RED



SAN GABRIEL MOUNTAINS

JUNE 22, 2016



**FALSE COLOR
COMPOSITE
REVEALS BURN
SCARS**

SAN GABRIEL MOUNTAINS

JUNE 22, 2016

