FRAM analysis on two spacecraft accidents

- The equivalence of failures and successes -

12 Jun 2018

Japan Manned Space Systems Corporation

Yasutaka Michiura

Objectives

How can we analyze accidents from success factors ?

Objectives

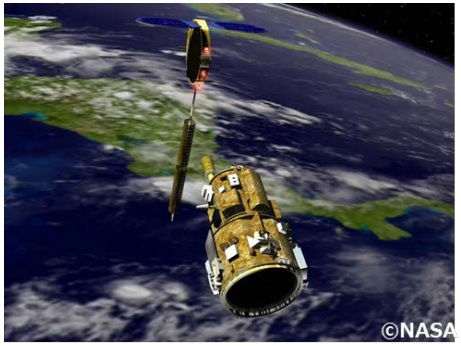
We applied FRAM analysis to two spacecraft systems:

- Experimental autonomous rendezvous/docking satellite "DART" of NASA.
- X-ray astronomical satellite "ASTRO-H" of JAXA

ASTRO-H

（source）
国立研究開発法人 宇宙航空研究開発機構（JAXA),
『X線天文衛星ASTRO-H「ひとみ」異常事象調査報告書 p.6』, 2016.6.14,
http://www.jaxa.jp/press/2016/06/20160614_hitomi_j.html

DART



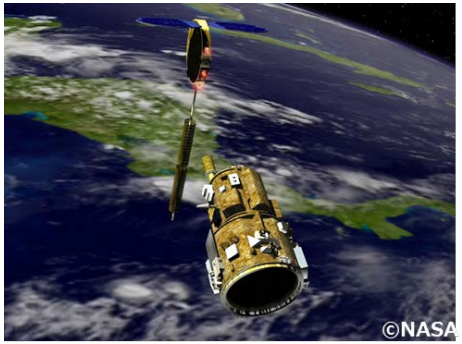
（source）
NASA,
http://mediaarchive.ksc.nasa.gov/detail.cfm?mediaid=23642

Outline

1. Characteristics of DART and ASTRO-H
2. Difference between DART and ASTRO-H
3. Success Factors and Risk Factors
4. Conclusion

ASTRO-H

DART

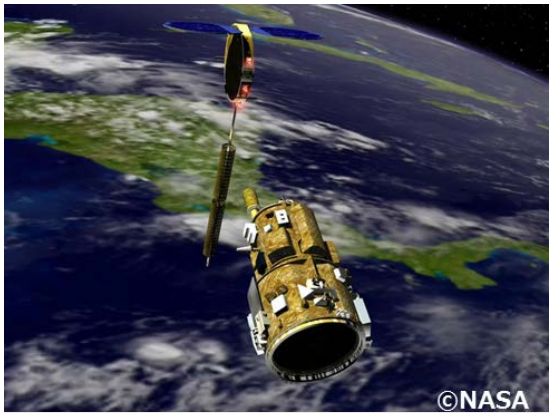


1. Characteristics of DART and ASTRO-H

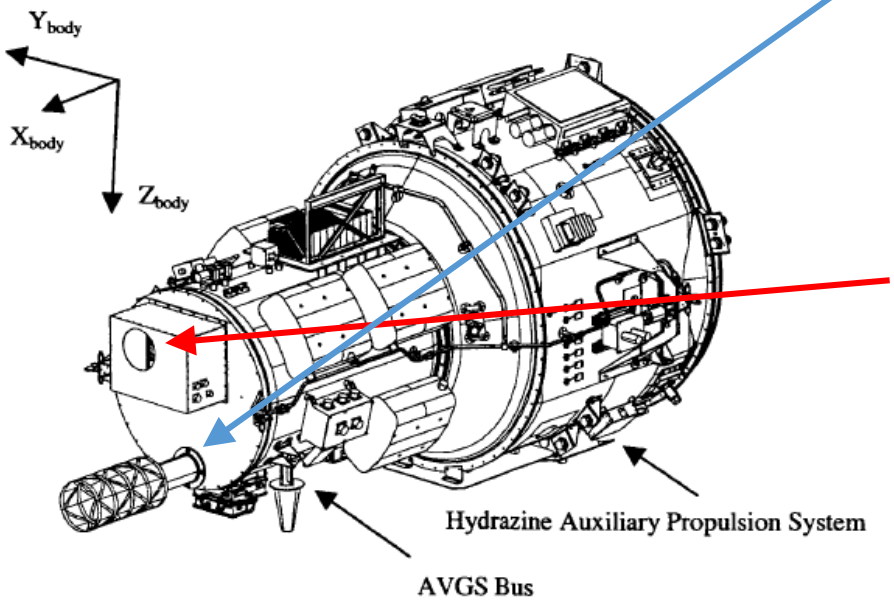
What's "DART" ?

- "DART" is earth orbiting satellite developed by NASA to test autonomous rendezvous technology.
- The satellite collided to its target satellite to be docked and depleted the fuel due to main position sensor incorporation.

DART



DART Onboard Sensor



GPS(Global Positioning System)：
The sensor identifies the position of the Satellite from the information of several GPS satellites.

Low accuracy sensor

AVGS(Advanced Video Guidance System)：
The sensor identifies the distance to the docking target satellite using optical information.

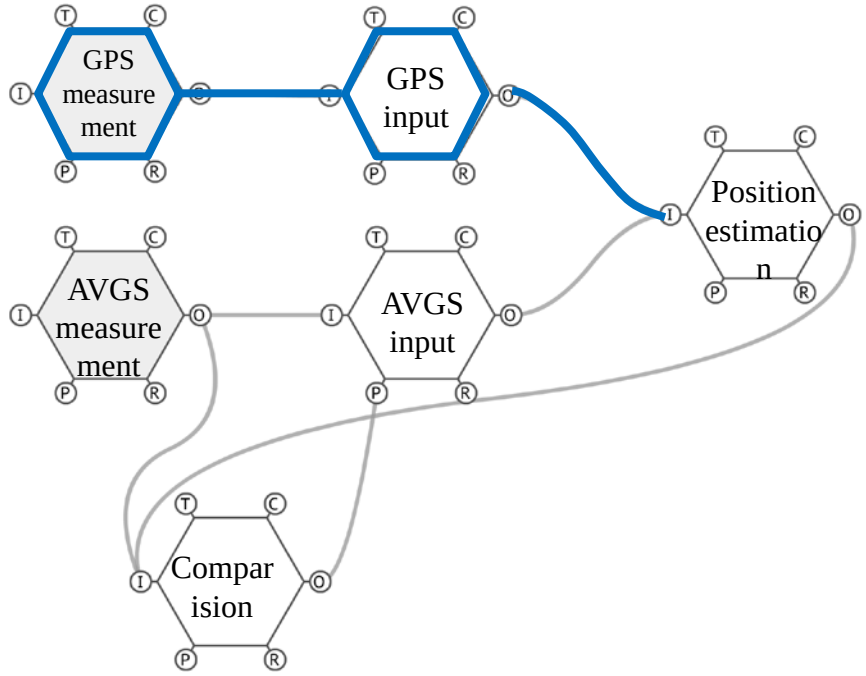
High accuracy sensor

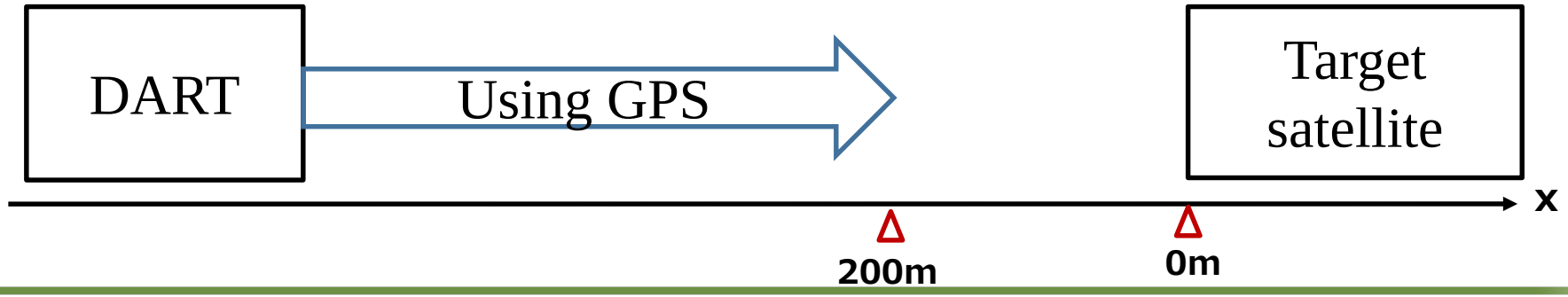
（Source）
Michael Ruth, Chisholm Tracy
Video-Guidance Design for the DART Rendezvous Mission,
Fig.4 DART Configuration

Characteristics of DART

- DRAT calculates the distance to the target satellite **using low accuracy sensor (GPS)** until it is sufficiently close to the target satellite.

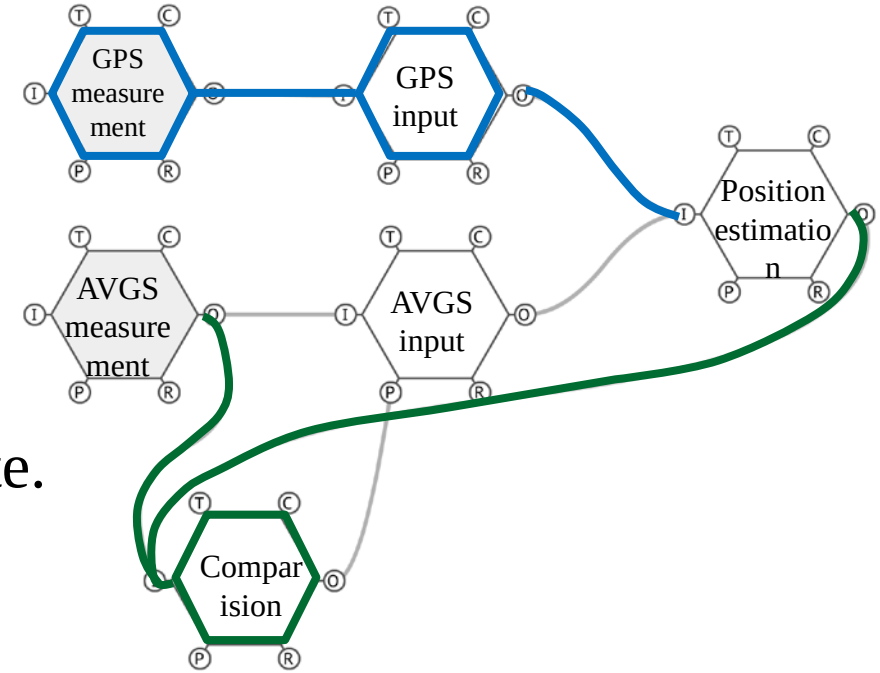
- Because it was thought that navigation is possible with GPS accuracy.



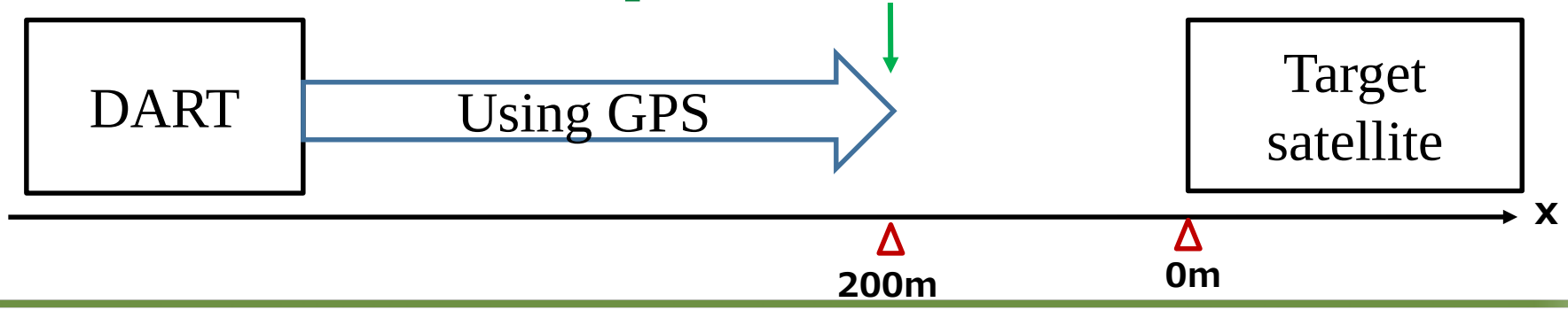


Characteristics of DART

- DART compares the GPS position estimation result with the AVGS measurement value.
- If both values are close, DART determines that it is close to the satellite.

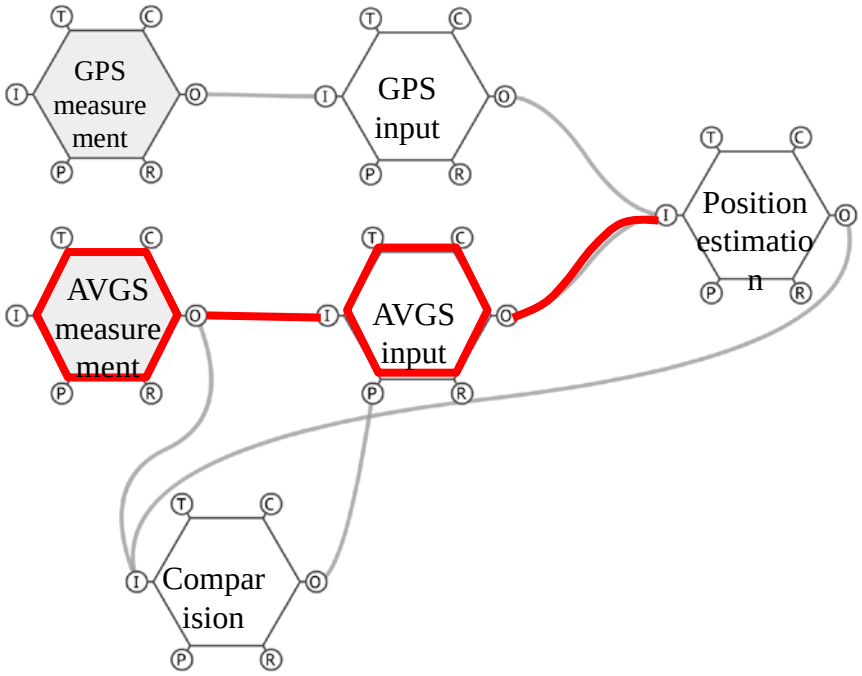


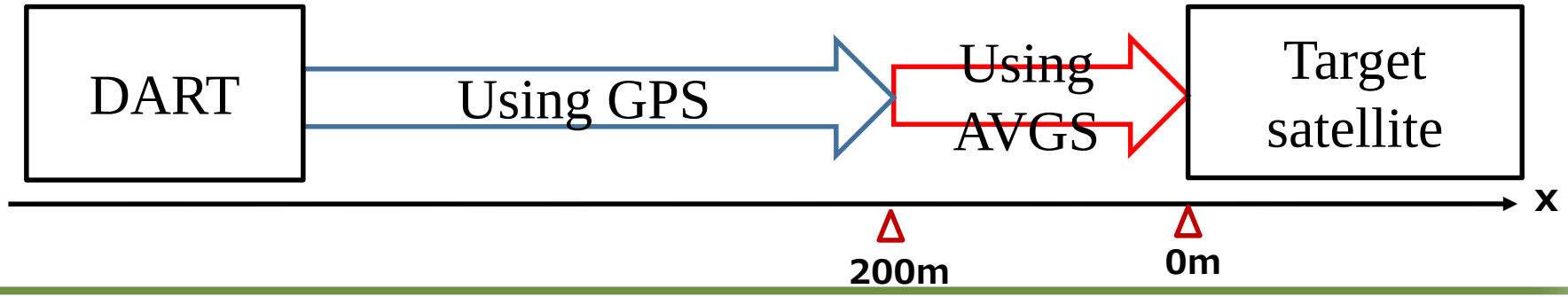
Comparison between GPS and AVGS



Characteristics of DART

- After sufficiently approaching the satellite, DART estimates the distance to the docking target satellite using the value of AVGS.



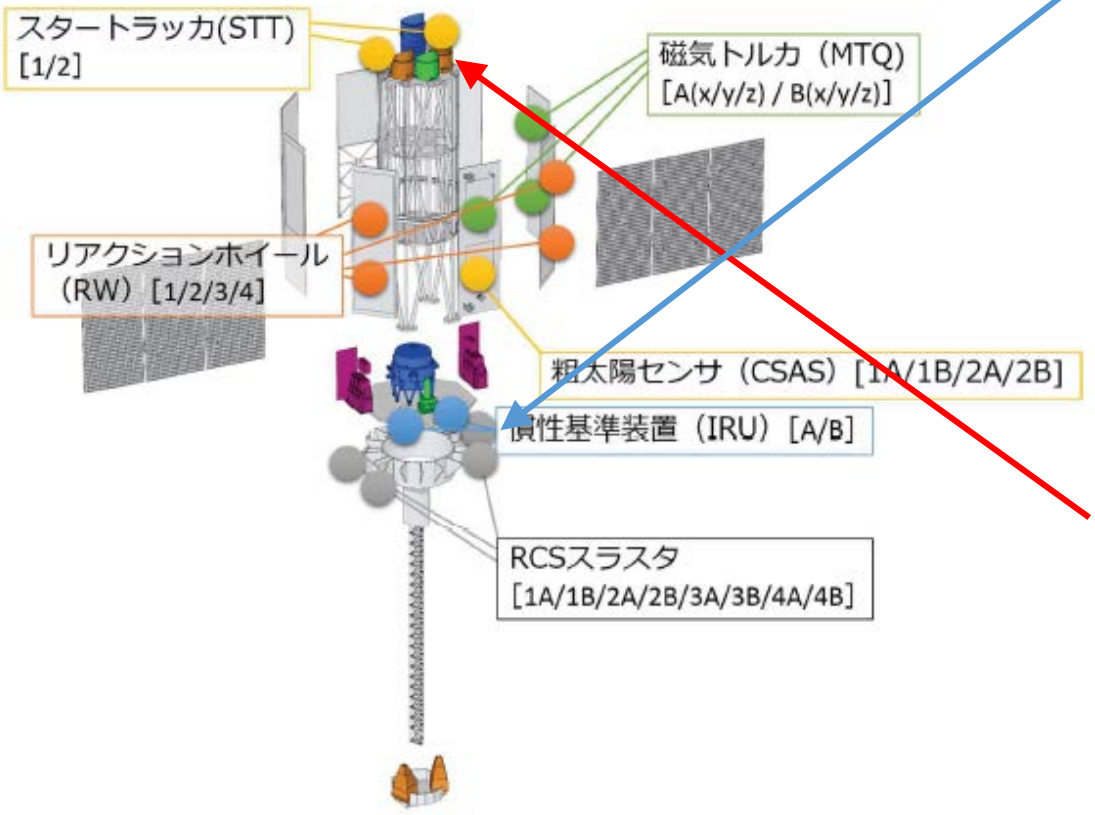


What's "ASTRO-H" ?

- "ASTRO-H" is astronomy satellite developed by JAXA to observe black holes, clusters of galaxies, etc.
- The satellite lost its attitude control and was destructed by excessive rotation rate due to main attitude sensor incorporation logic.

ASTRO-H

ASTRO-H Onboard Sensor



IRU(Inertial reference unit)：
The sensor detects the acceleration and rotation state of the satellite and specifying the position and attitude information of the satellite.

Low accuracy sensor

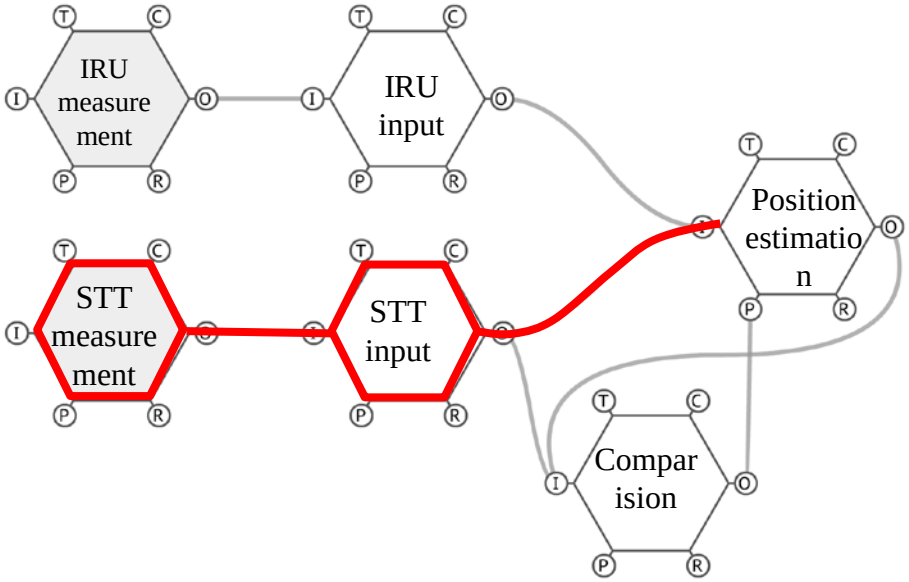
STT(Star Tracker)：
The sensor identifies the position and attitude information of the satellite using position information of multiple stars.

High accuracy sensor

（Ref.）
国立研究開発法人 宇宙航空研究開発機構（JAXA),
『X線天文衛星ASTRO-H「ひとみ」異常事象調査報告書 p.11』, 2016.6.14,
http://www.jaxa.jp/press/2016/06/20160614_hitomi_j.html

Characteristics of ASTRO-H

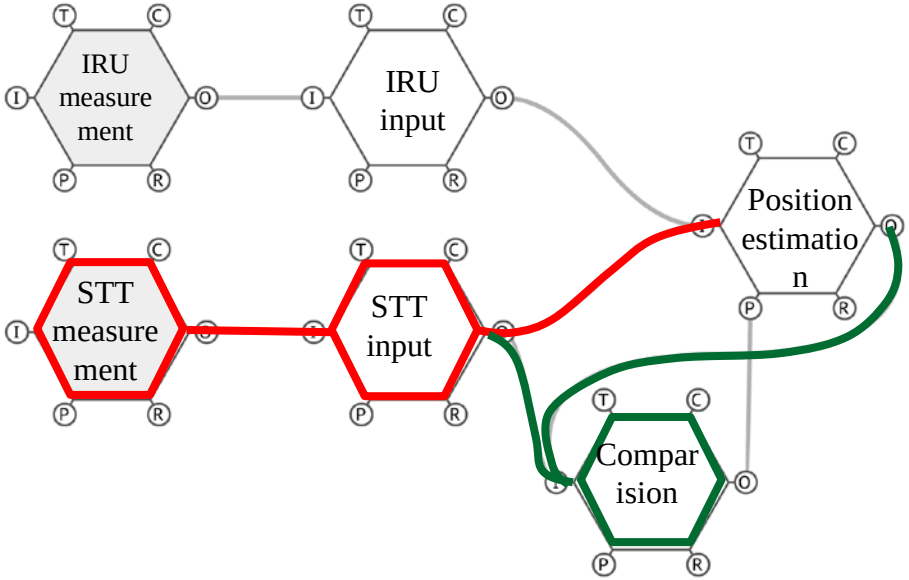
- ASTRO-H is necessary to control the attitude of the satellite with high accuracy.
- Because ASTRO-H is astronomical satellite for photographing distant stars.
- Therefore, the satellite **usually uses highly accuracy sensor (STT).**



Normally, ASTRO-H navigates using the value of STT.

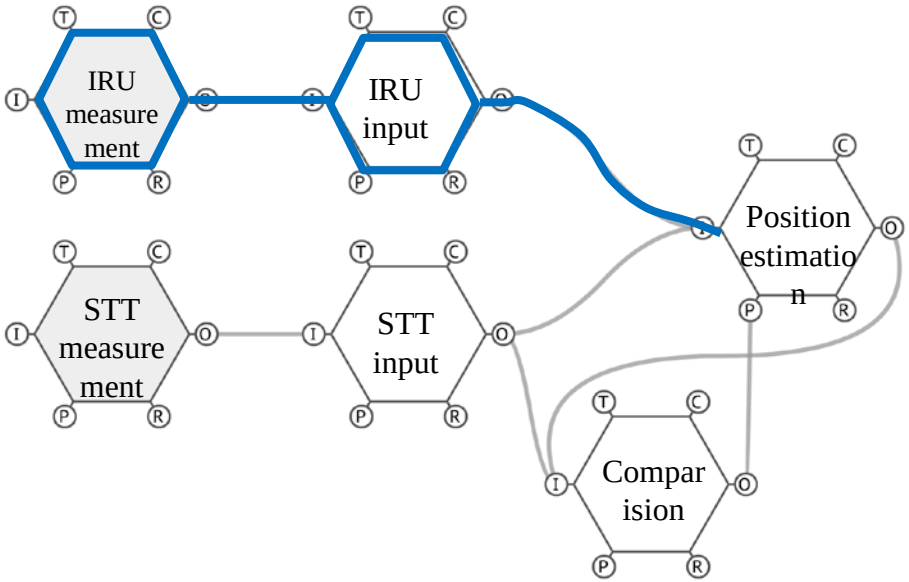
Characteristics of ASTRO-H

- In order to confirm the accuracy of STT, ASTRO-H compares the input data of STT with position estimation result with IRU.



Characteristics of ASTRO-H

- When the accuracy of the STT declines and it becomes unusable, ASTRO-H estimates the attitude of the satellite by using the low accuracy sensor (IRU).



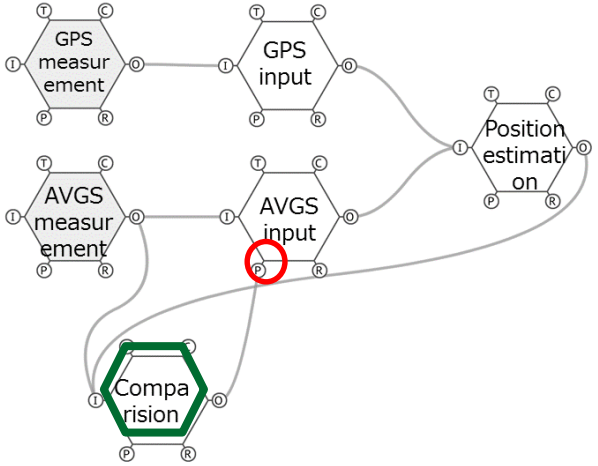
ASTRO-H navigates using the value of IRU when STT can not be used.

2. Difference between DART and ASTRO-H

Difference between DART and ASTRO-H

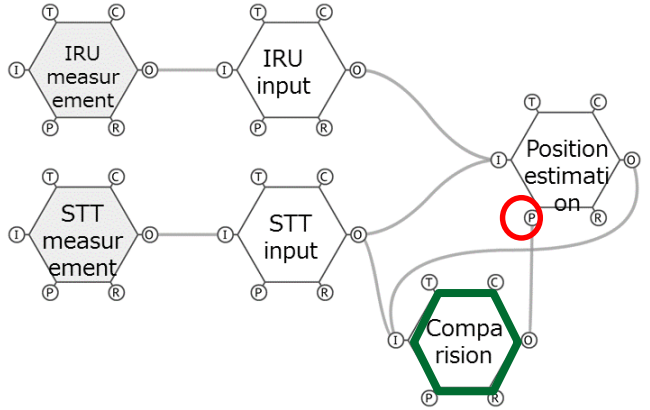
DART

DART compares the measured values of high accuracy sensor(AVGS) **before** incorporating, and if it is NG, does not capture the measured value.



ASTRO-H

ASTRO-H compares the measured values of high accuracy sensor(STT) **after** incorporating, and if it is NG, does not capture the measured value.



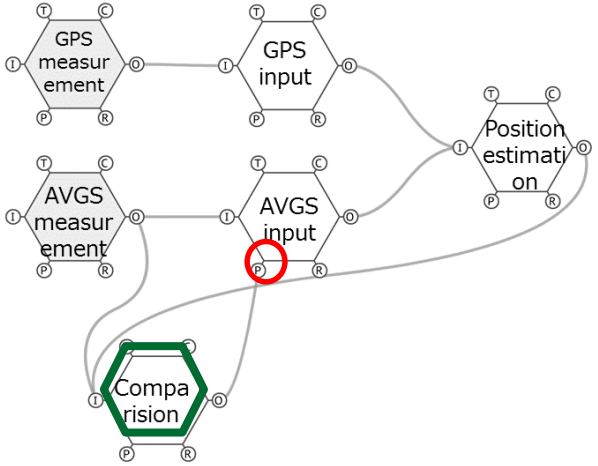
The timing to check the input data is different.

3. Success factors and Risk factors

Cause of Accidents

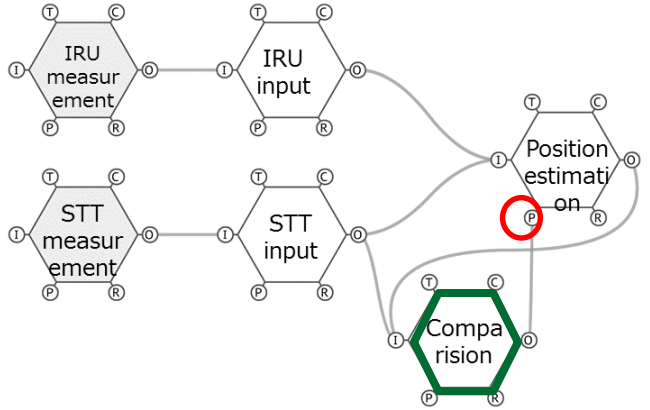
DART

DART collided with target satellite, because the value of low accuracy sensor(GPS) could not converge.



ASTRO-H

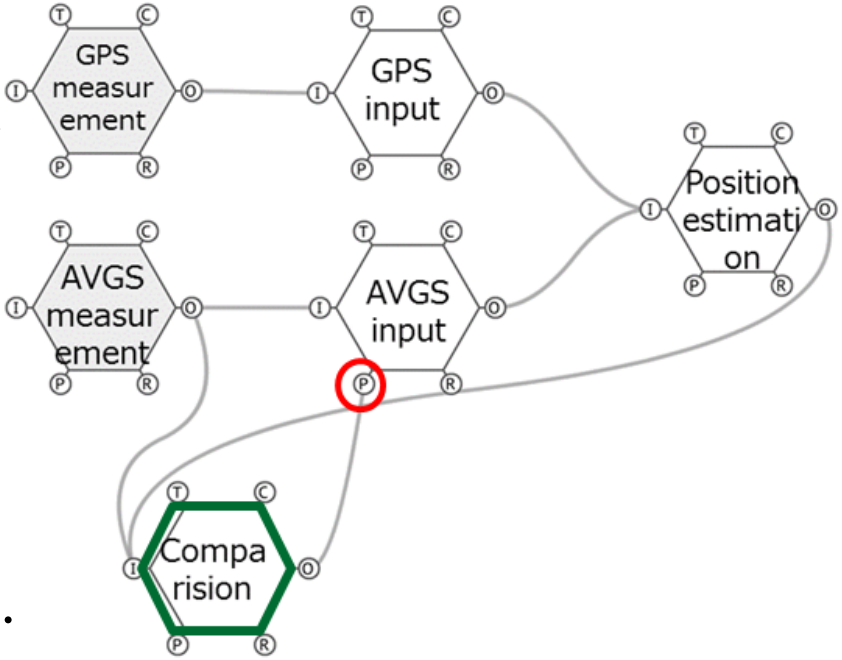
ASTRO-H lost its attitude control, because the satellite used the value of high accuracy sensor (STT) before the value converged.



DART

Success factors：

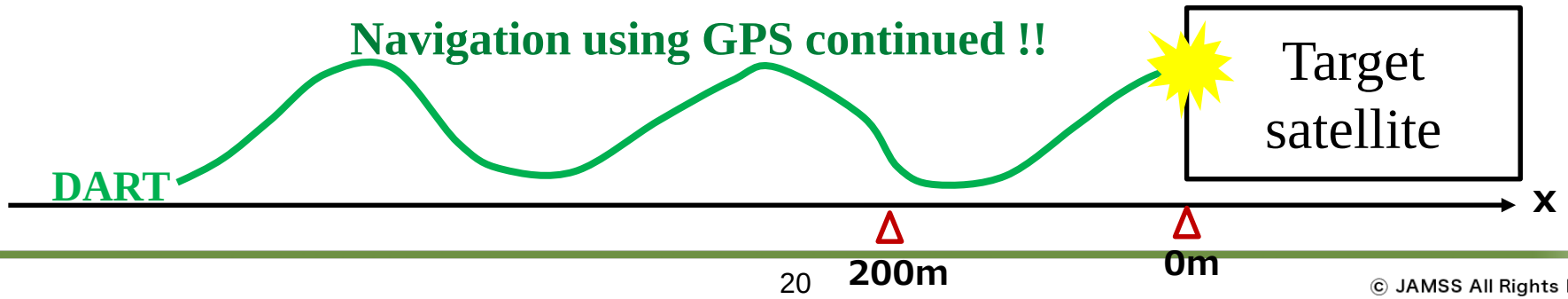
DART can rely on low accuracy GPS until final phase transition to use high accuracy AVGS. Final phase transition is performed carefully before decide to use high accuracy AVGS .



Risk factors：

If the accuracy of GPS is low, the comparison always becomes NG and AVGS can not be used.

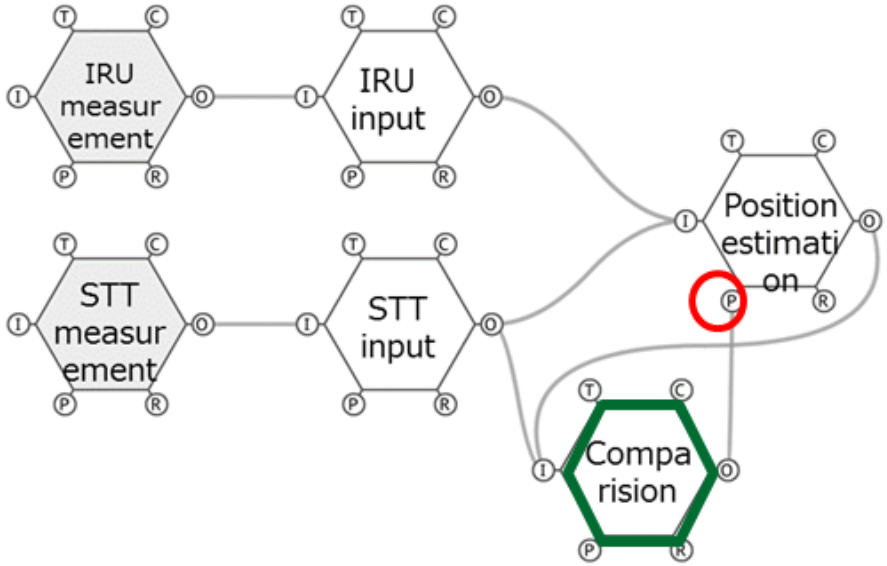
⇒Cause of collision of DART



ASTRO-H

Success factors ：

ASTRO-H has to rely on high accuracy STT as soon as possible, because the satellite needs to achieve super accurate attitude control.



Risk factors ：

When Navigation of ASTRO-H switches from low accuracy IRU to high accuracy STT, the navigation value greatly changes.

⇒Cause of loss of navigation

ASTRO-H

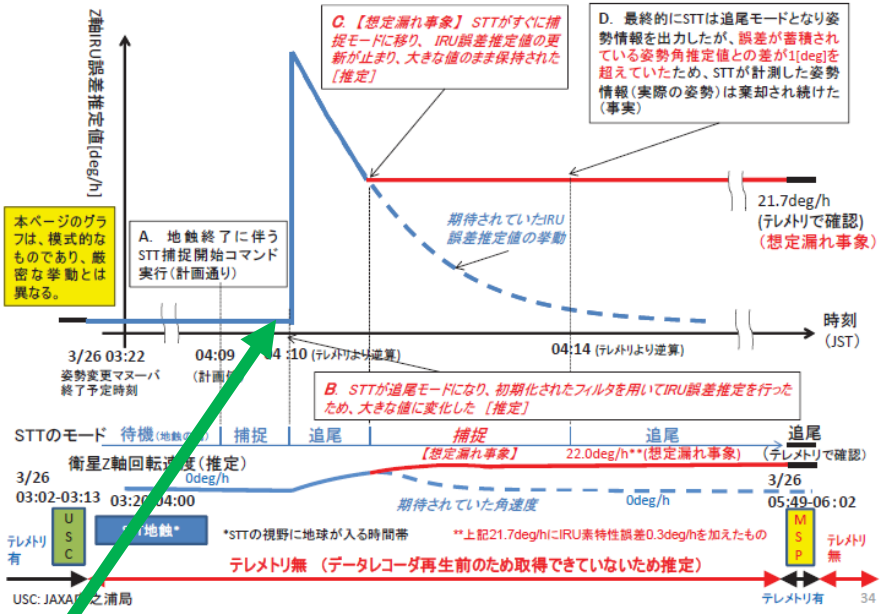
Success factors ：

ASTRO-H has to rely on high accuracy STT as soon as possible, because the satellite needs to achieve super accurate attitude control.

Risk factors ：

When Navigation of ASTRO-H switches from low accuracy IRU to high accuracy STT, the navigation value greatly changes.

⇒Cause of loss of navigation



(source)
国立研究開発法人 宇宙航空研究開発機構（JAXA),
『X線天文衛星ASTRO-H「ひとみ」異常事象調査報告書 p.34』, 2016.6.14

The data used to navigation suddenly switched from IRU to STT

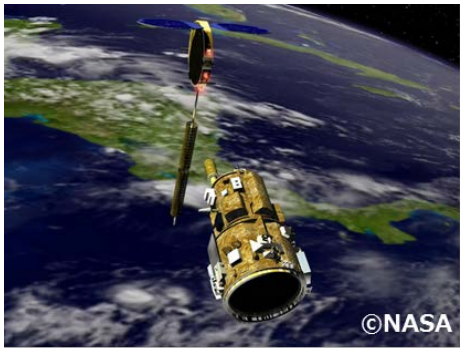
4. Conclusion

Conclusion

DART

DART can rely on low accuracy GPS until final phase transition to use high accuracy AVGS.
Final phase transition is performed carefully before decide to use high accuracy AVGS .

DART

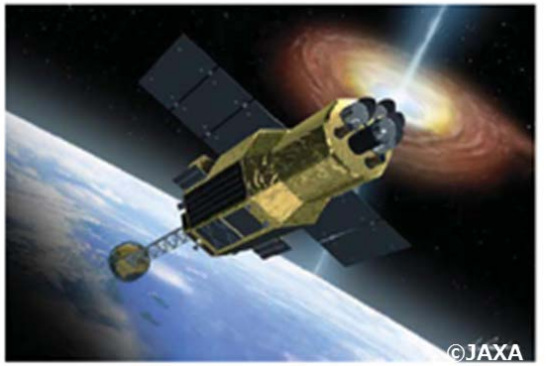


⇒ Success pattern of earth orbiting satellite

ASTRO-H

ASTRO-H has to rely on high accuracy STT as soon as possible, **because the satellite needs to achieve super accurate attitude control.**

ASTRO-H

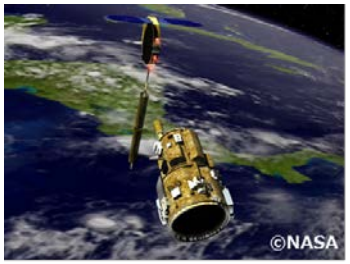


⇒ Success pattern of astronomical satellite

Conclusion

There are risk behind the success factor of each satellite.

DART



Success factors

DART satisfied safety requirement by relying on low accuracy GPS.

Risk factors

When the value of GPS gets worse, safety requirements can not be satisfied.

ASTRO-H

ASTRO-H has to rely on high accuracy STT.

When Navigation of ASTRO-H switches from low accuracy IRU to high accuracy STT, the navigation value greatly changes.

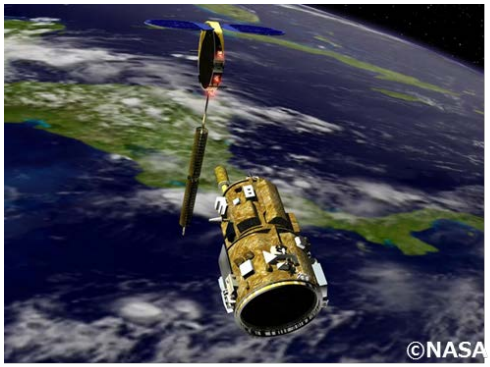
Each success factor has become a cause of each accident.

Conclusion

- There were no accidents similar to the two satellites in the past.
- Therefore, it is difficult to implement safety analysis based on defects.

ASTRO-H

DART



It is necessary to identify the success factor of the system and identify the risk behind it.

References

- NASA, “Overview of the DART Mishap Investigation Results”, https://www.nasa.gov/pdf/148072main_DART_mishap_overview.pdf
- NASA, “DART Risk Management Case Study”
- Michael Ruth, Chisholm Tracy, “Video-Guidance Design for the DART Rendezvous Mission”, 2004
- JAXA, ”X線天文衛星ASTRO-H「ひとみ」異常事象調査報告書” ,2016, http://www.jaxa.jp/press/2016/06/20160614_hitomi_j.html