JAXA's Research and Development of Unmanned Aircraft System Technologies for a Disaster Risk Reduction

Japan Aerospace Exploration Agency (JAXA)
Aeronautical Technology Directorate
Daisuke Kubo

Introduction of JAXA, Aeronautical Directorate

Aeronautical field and centers of ATD/JAXA

Taiki Aerospace Research Field
(1000 x 30 m)

Chofu Aerospace Center
(Chofu airport, 800 x 30 m)

Nagoya Flight Research Center
(Nagoya airport, 2740 x 45 m)

Introduction of JAXA, Aeronautical Directorate

Three programs and basic research area

Recent R&D related to UAS in JAXA

2003 - 2007	2008 - 2012	2013 - 2017	2018 - 2022

Disaster Monitoring UAS

Weather Observation UAS

Remote Sensing UAS

Radiation Monitoring UAS (UARMS)

Safety Technologies for sUAS

HALE-UAS

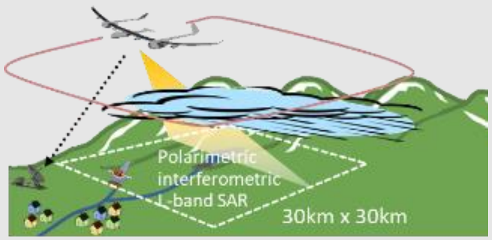
Unmanned aircrafts for aerospace technology demonstration

Reentry Vehicle Technology (ALFLEX, HSFD)

Tiltwing VTOL

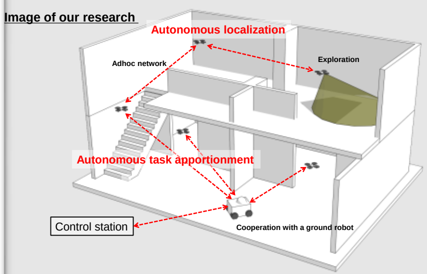
Aerodynamics for Supersonic Transport (NEXST-1, D-SEND)

This talk includes... ongoing 4 UAS R&Ds

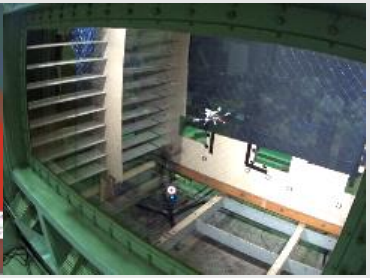



I. High altitude long endurance UAS conceptual study (2011-)


II. Small UAS radiation monitoring for Fukushima (2011-)

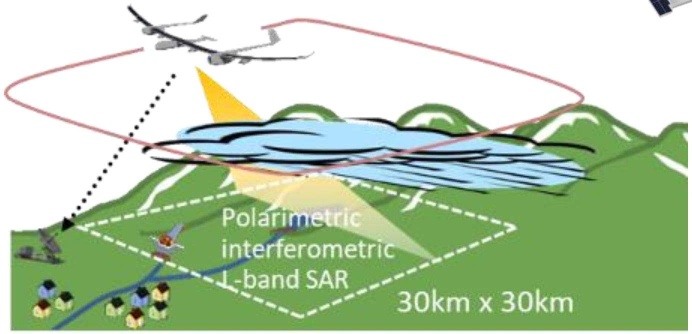


III. Multiple MAV corporative mission capability (2012-)

IV. UAS traffic management and flight performance (2015-)

I. High Altitude Long Endurance UAS Conceptual Study

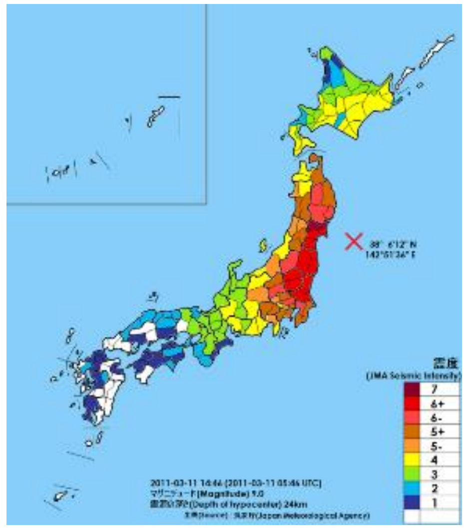


I. High Altitude Long Endurance UAS Study

Background: Northeast Japan Huge Earthquake, 2011

Sendai airport[1)]

Miyagino-ku, Sendai-city[1)]

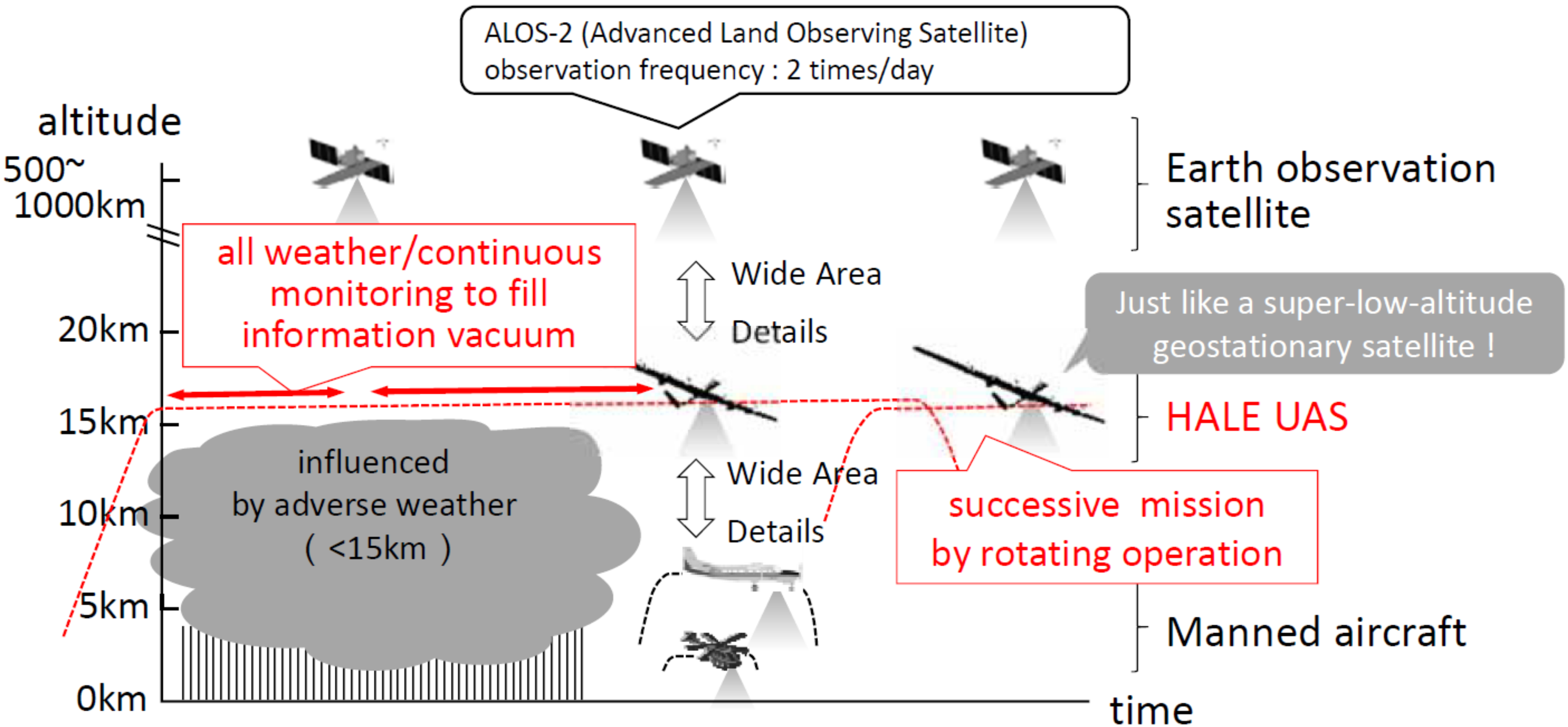


Miyagino-ku, Sendai-city[1)]

1) https://ja.wikipedia.org/wiki/%E6%9D%B1%E6%97%A5%E6%9C%AC%E5%A4%A7%E9%9C%87%E7%81%BD

- Seismic intensity 9.0 (the Richter scale)
- Number of missing and dead: 18,446
- **Largest earthquake in Japan especially wide areas**
- **Huge tsunami, wide area**
- Resulting nuclear power plant accident
- **There is "small number" of actual use of UAS**

HALE UAS for a “continuous mission” platform



I. High Altitude Long Endurance UAS Study

Target Flight Performance

Operating Altitude

- above typhoon and cumulonimbus
- above the airspace of manned aircraft

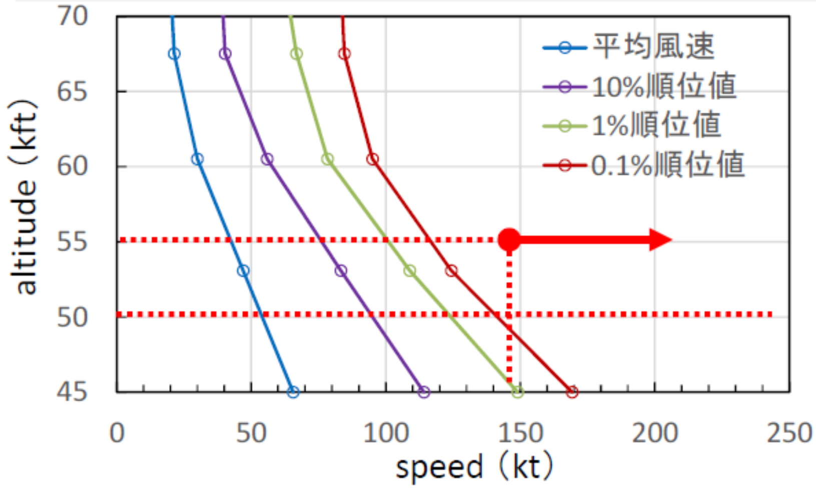
→ 55 - 60kft (16.5 - 18km)

Cruise / Max. Speed

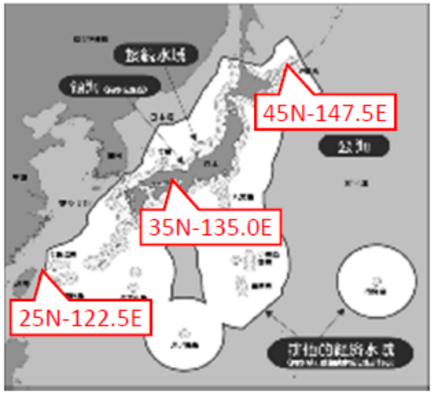
- more than 99.9% wind + 50kt* at operating altitude

* ground speed needed for SAR

→ 150kt (max. 210kt) (280 - 390km/h)



Wind data :
NCEP Reanalysis data
at 3 locations, 2000-2009



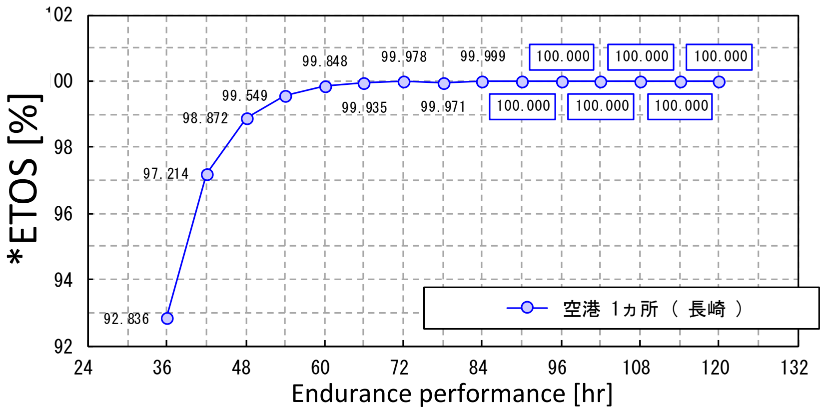
Endurance

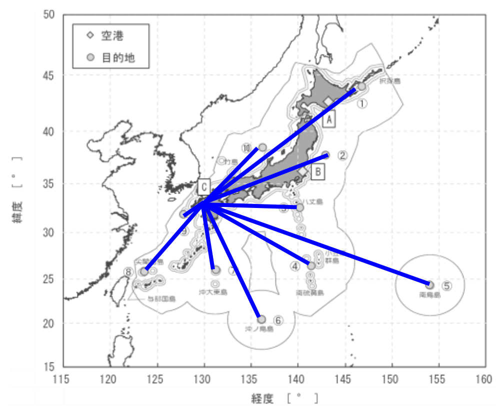
- Effective Time On Station, ETOS ≒100%

→ 72hr

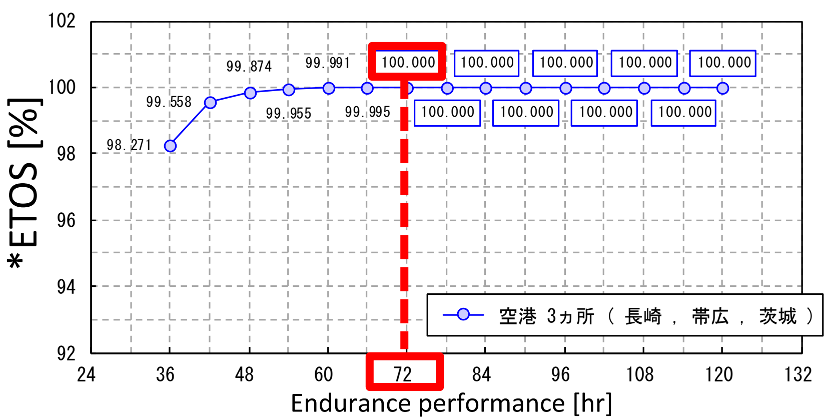
Operation analysis based on past airport weather data

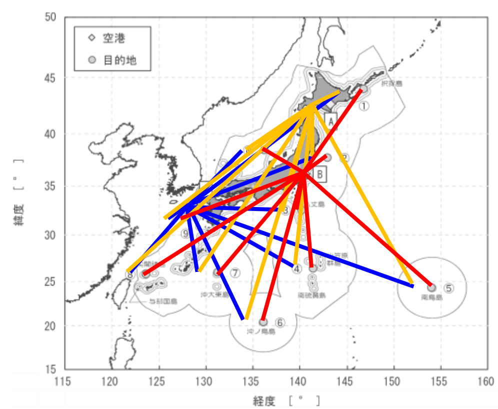
Single airport operation





Multiple airports operation





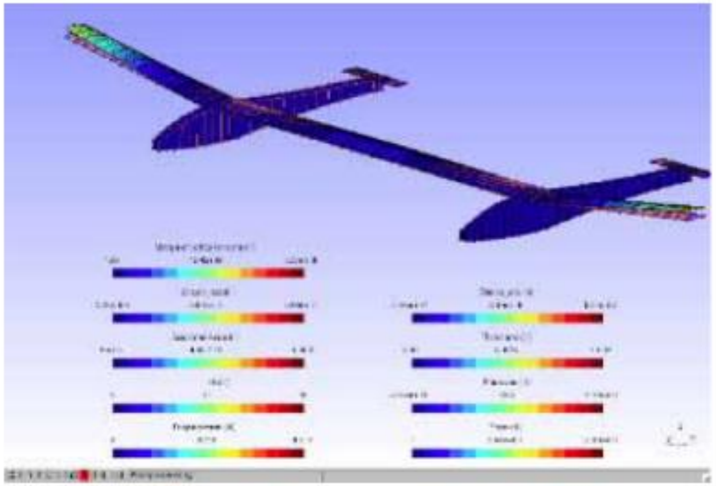
- Rotational operation
- Constraint of airport weather (cross wind and visibility)
- Cover exclusive economic zone of Japan
- **72 hours endurance enables continuous operation capability**

*ETOS: Effective Time On Station

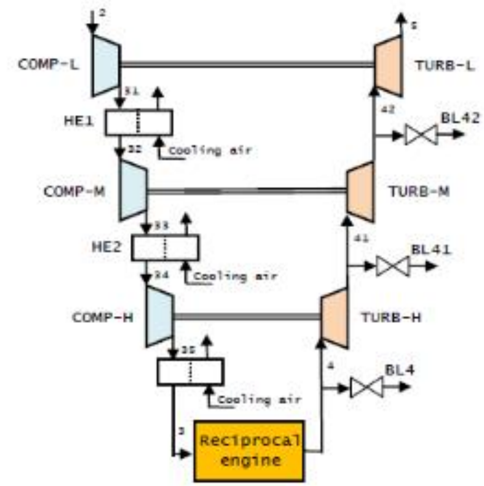
Technological challenges to realize the flight performance

Wing span	46 m
MTOW	3.7 t
Payload	> 200 kg
Mission altitude	> 55kft (16.5 km)
Cruising speed	> 150 knots
Endurance	72 hours

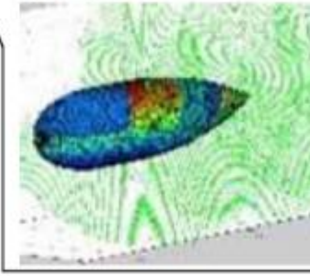
Lightweight airframe structure



Multi-stage turbocharged diesel reciprocating engine

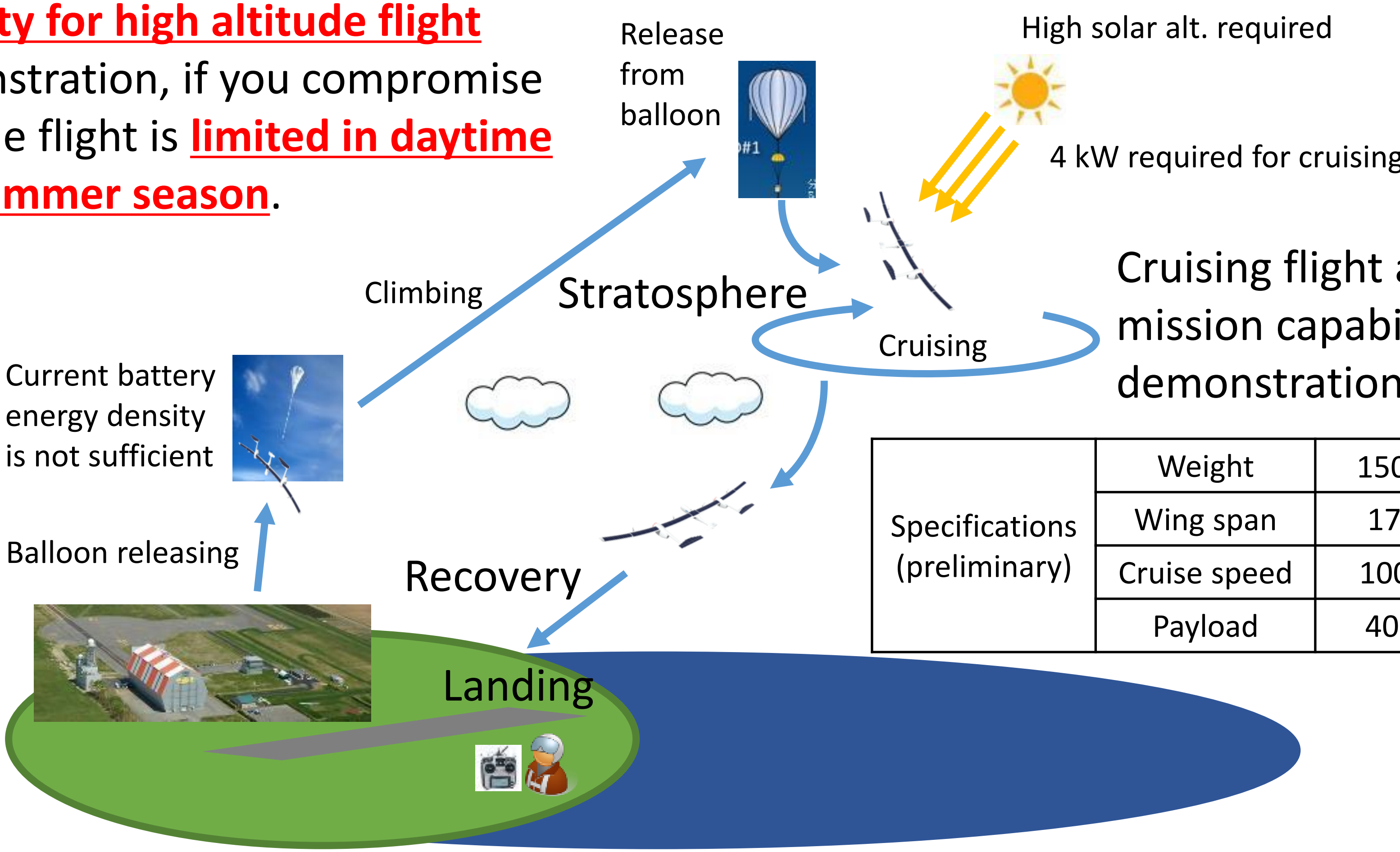


Low-Re propeller



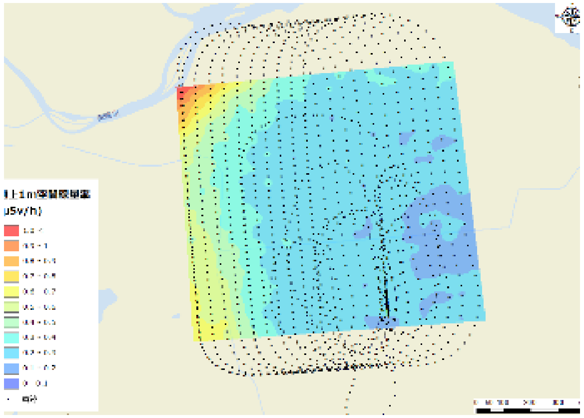
Small scaled HALE demonstration platform (preliminary)

Solar-powered high-speed airplane allows **large experimental-payload capacity for high altitude flight** demonstration, if you compromise that the flight is **limited in daytime and summer season**.



Specifications (preliminary)		
	Weight	150 kg
	Wing span	17 m
	Cruise speed	100 kt
	Payload	40 kg

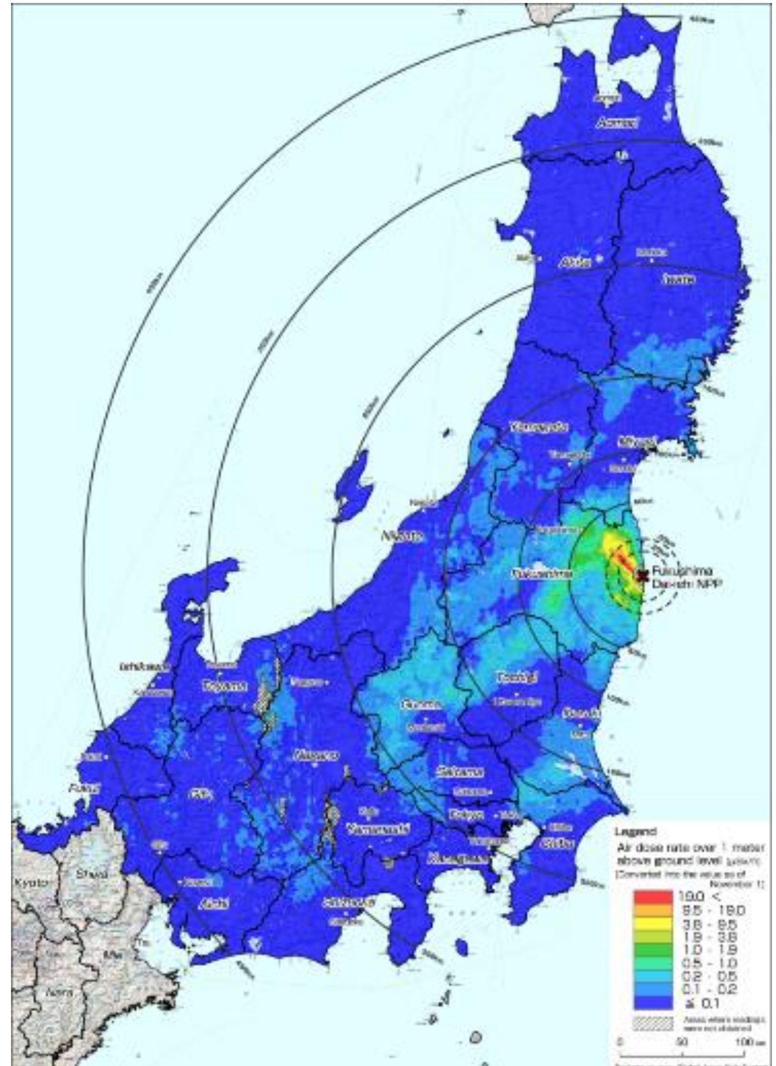
II. Fixed Wing UAS for Radiation Monitoring



JAEA: Japan Atomic Energy Agency
UARMS: Unmanned Airplane for Radiation Monitoring System

Background: Nuclear Accident and Radiation

- ✓ Radiation monitoring using manned helicopters
- ✓ Continuous mission, not only once, but every year for monitor the variation
- ✓ A number of flights are required



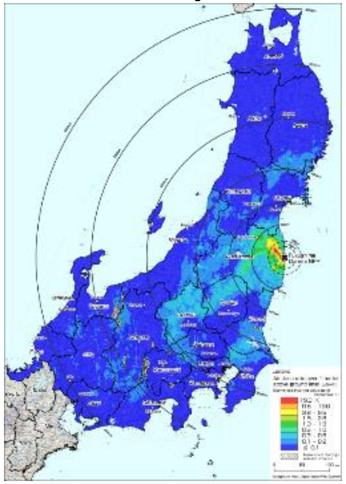
II. Fixed Wing UAS for Radiation Monitoring

UARMS project with the Japan Atomic Energy Agency (JAEA)

Range	Wide >100 km	Middle >10 km	Local ～1 km	Site ～100 m
Platform	Manned helicopter	Fixed wing UAS	Rotary wing UAS	Small UAS
Altitude	～300 m	～150 m	～50 m	～10 m

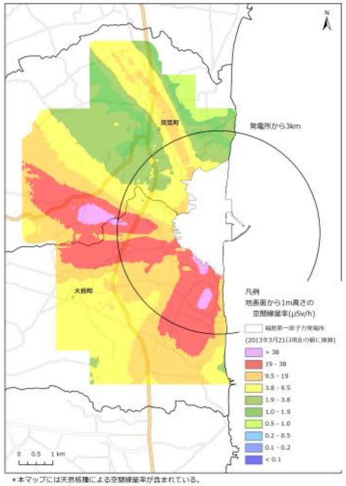
JAEA developing

Wide area map



Middle area and rapid response in emergency (ex. forest fire)

1) http://www.japantimes.co.jp/wp-content/uploads/2017/05/n-fukufire-a-20170512-870x650.jpg

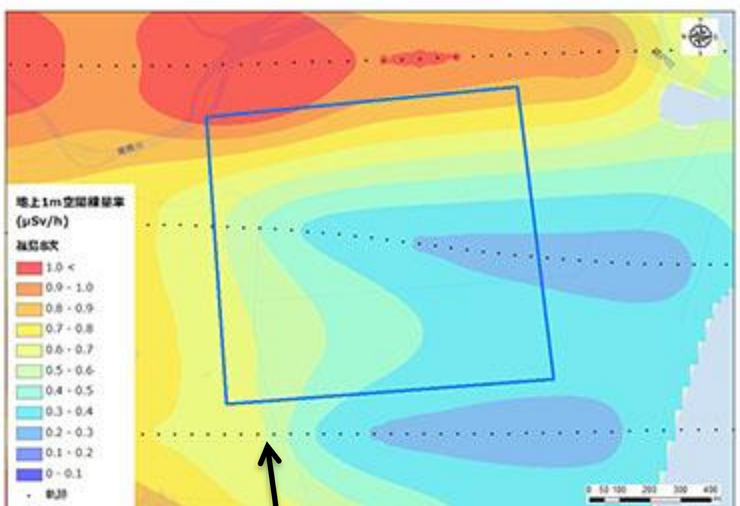


Local area detailed map

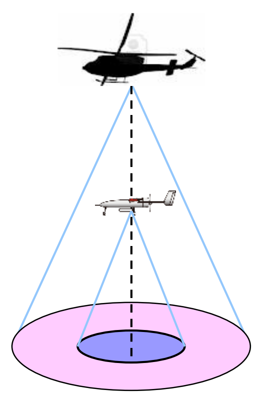
Radiation map obtained by fixed wing small UAS

- ✓ World first application of fixed wing UAS for radiation map construction in 2014
- ✓ UAS has large benefit compared to manned aircraft
  - ✓ Low altitude, repeatable flight path, precise terrain following, etc.
- ✓ Miniaturization of precision radio detector is also key factor

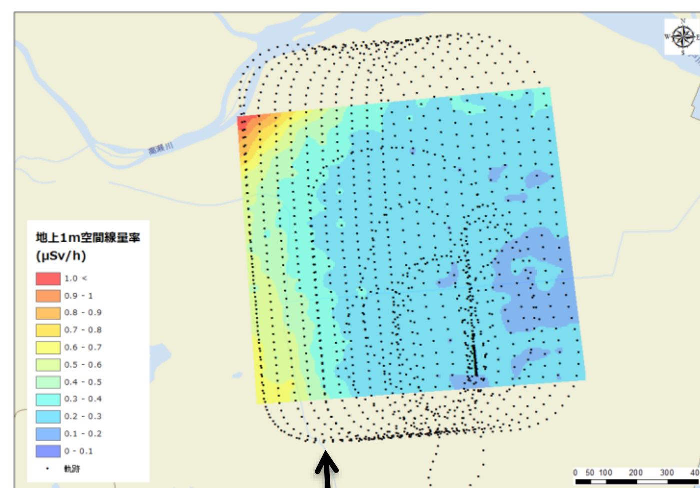
Manned helicopter = AGL 300 m



Dot line: low density and flight patterns



UARMS < AGL 150 m

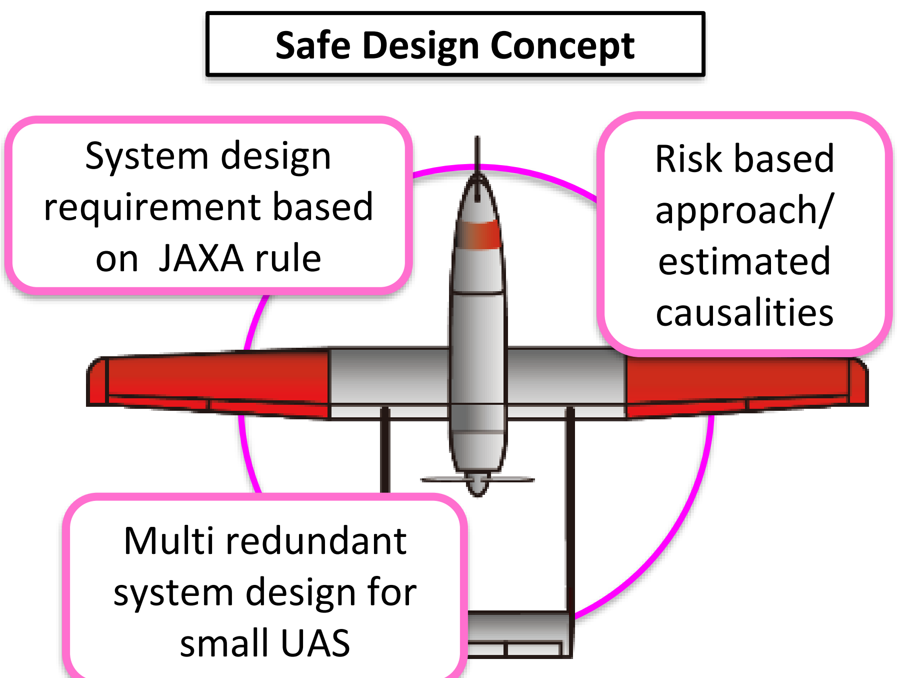


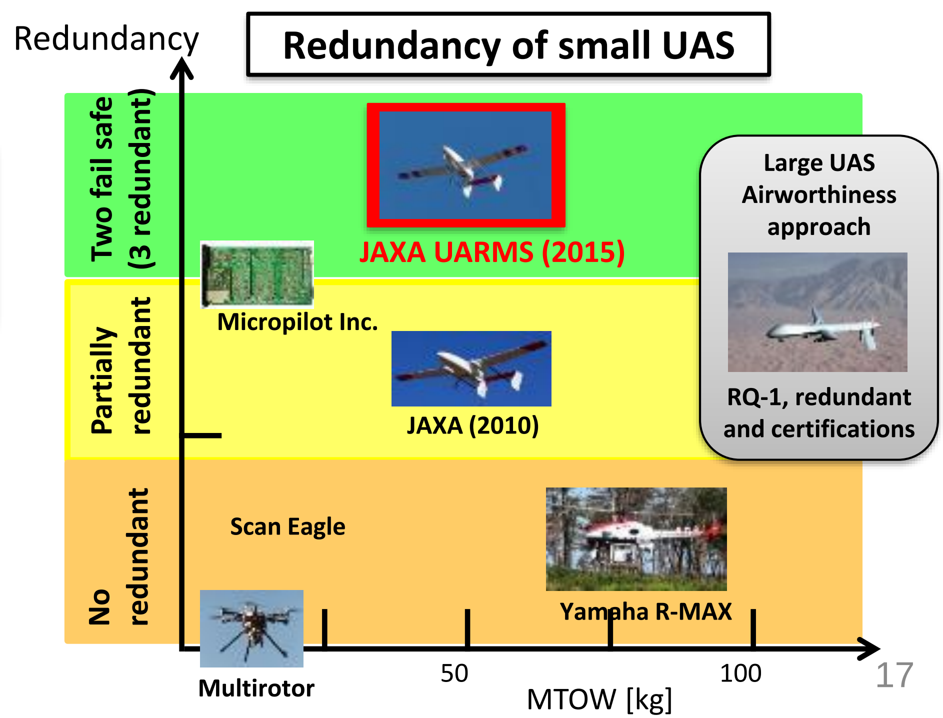
Dot line: high density flight patterns

II. Fixed Wing UAS for Radiation Monitoring

Safe Design Concept

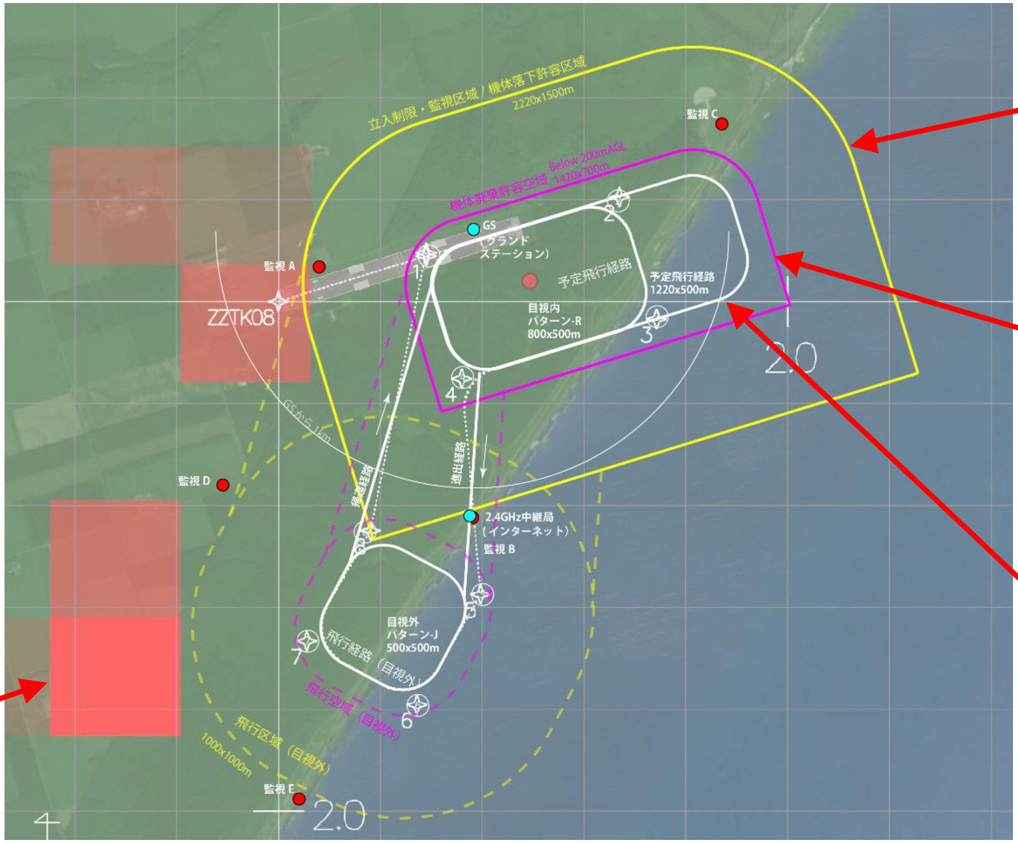
- ✓ Multi redundant design, two fail safe to catastrophic hazard
- ✓ Design requirement defined in JAXA rule
- ✓ Reliability evaluations based on operational data
- ✓ Beyond Visual line of Sight (BVLOS) operation planned



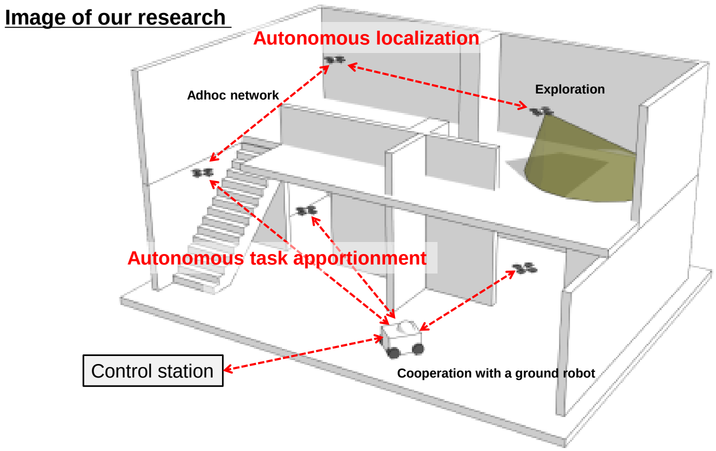


Operation example: BVLOS flight demonstration

- ✓ JAXA Taiki Aerospace Research Field
- ✓ Safety management based on risk: “reliability of UAS” x “population density” (maximum population density = $0.4/km^2$)



III. Multiple MAV Corporative Mission Capability

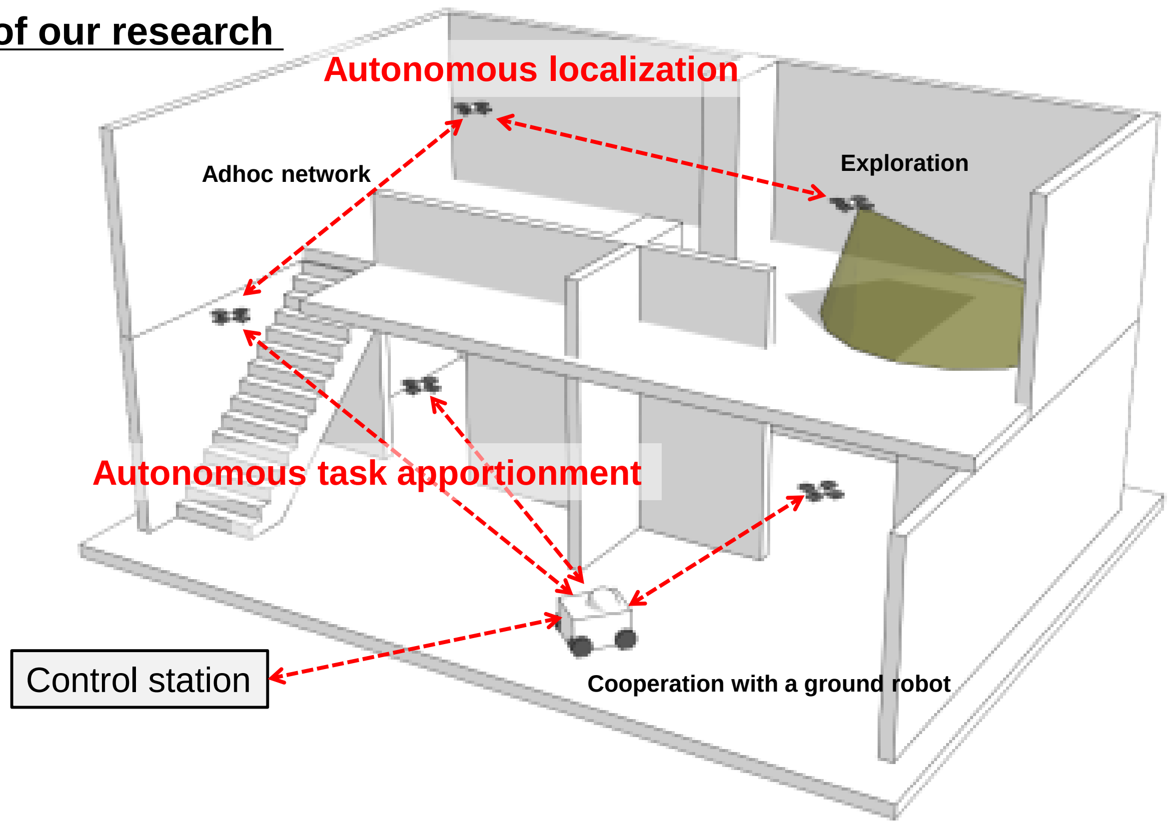


III. Multiple MAV Corporative Mission Capability

Technical challenges

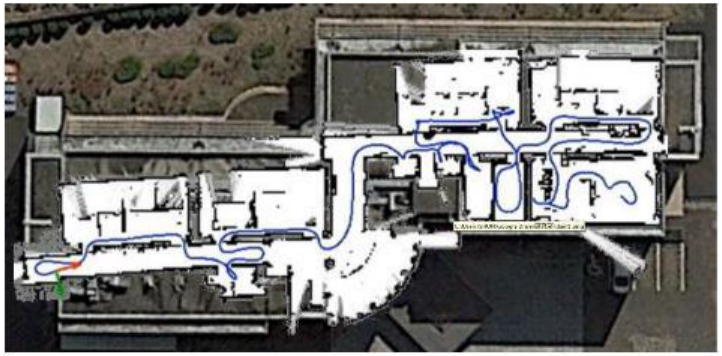
- ✓ GPS denied navigation (multiple SLAM, advanced optic flow)
- ✓ Cooperative motion planning algorithms: simple and robust rule-based, greedy-approach, and distributed algorithm
- ✓ Safe flight platform for indoor environment

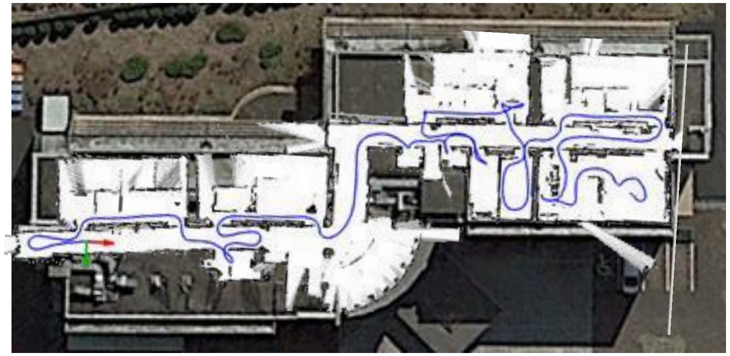
<u>Image of our research</u>



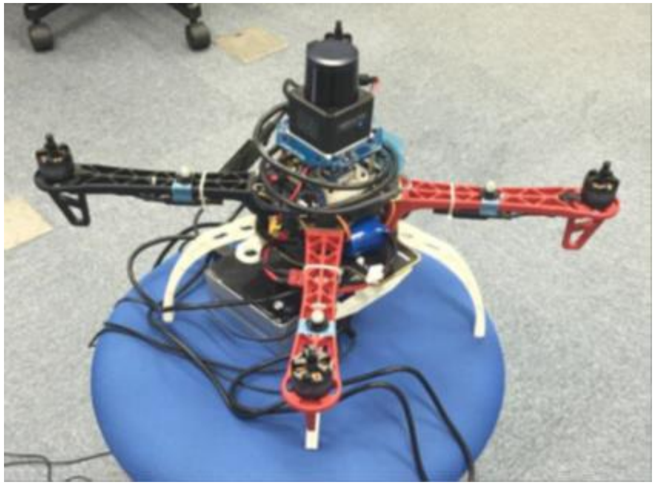
GPS Denied Navigation

- ✓ SLAM: simultaneous localization and mapping
- ✓ Developed in ground robotics area and recently applied for MAV
- ✓ Challenge: multiple flying vehicle data real-time integration





SLAM occupancy grid map overlaid on actual building
Distortions are issue that is currently addressed via loop closing technique



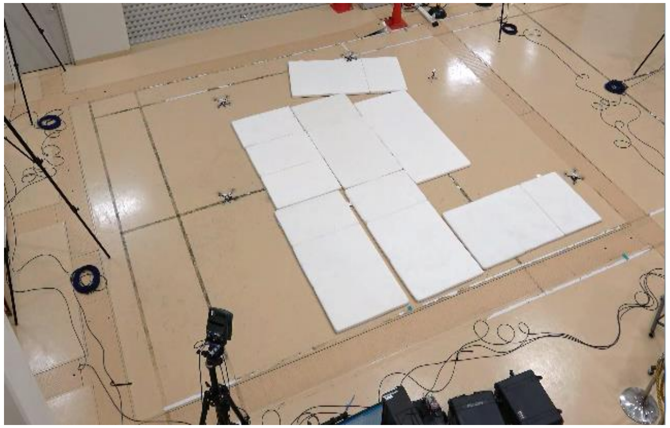
Small Lidar equipped MAV for SLAM research

III. Multiple MAV Corporative Mission Capability

Cooperative motion planning algorithms

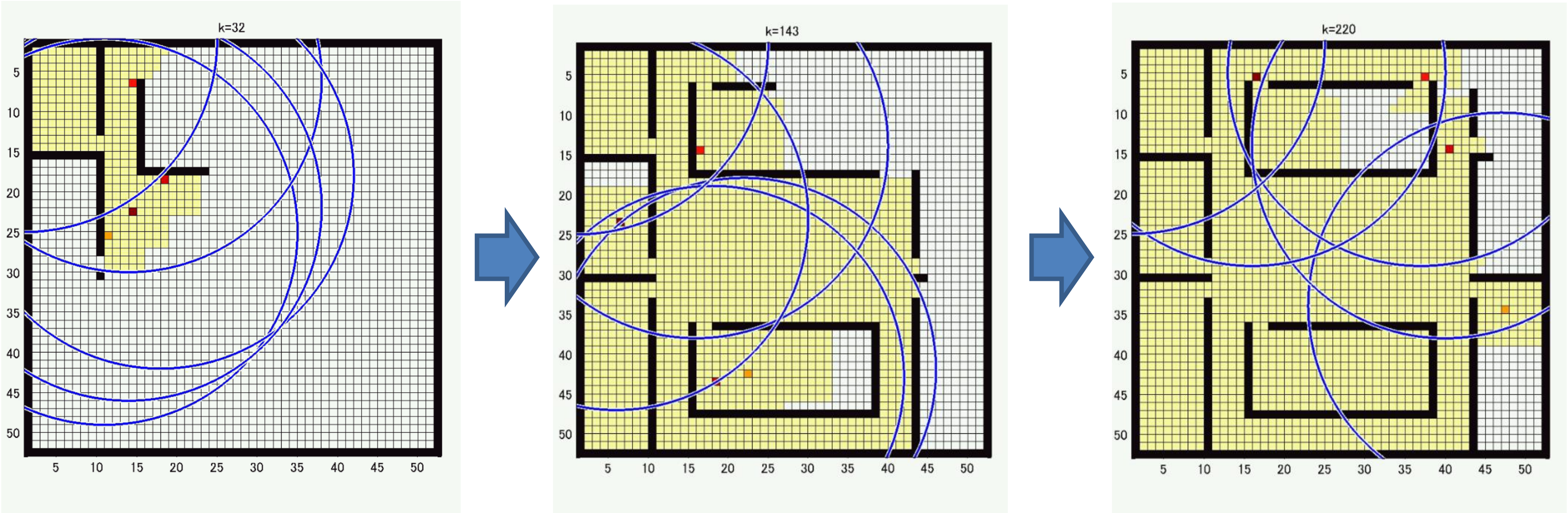
- ✓ Simple and robust rule-based
- ✓ Greedy-approach
- ✓ Distributed algorithm for multipole MAVs operation

Real time HILS



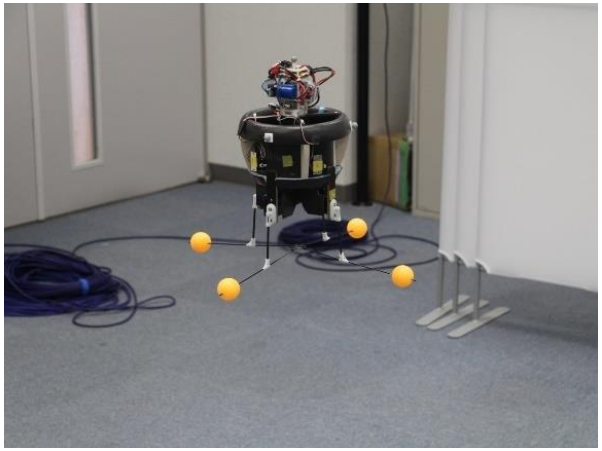
Simulation of the algorithm

Red dot: MAV, **Blue circle**: communication relay constraint



More safe platform technologies: ducted-fan type MAV

Palm-sized single ducted fan flying robot has a high level of safety because of the shrouded propeller, which is harmless to ground objects and people.
The undesired noise because of the high speed rotation and interference of duct structures will be the biggest problem and the research task.



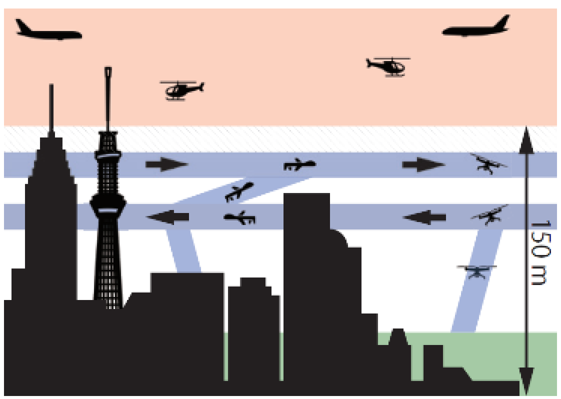
15 cm-duct-diameter ducted fan MAV

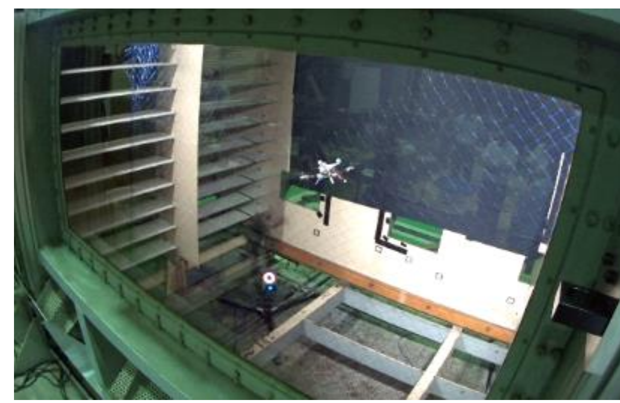
10 cm-duct-diameter ducted fan MAV

Video

Smaller **7.5 cm**-duct-diameter ducted fan MAV

IV. UAS Traffic Management and Flight Performance





IV. UAS Traffic Management Study

Background: BVLOS flight for nuclear reconnaissance

Fuji-imvac Type B[1)]

Fukushima dai-ichi nuclear power plant[1)]
03/20/2011 (9 days after the accident)

1) http://www.yamazaki-k.co.jp/airphoto/concept.html

- BVLOS (beyond visual line of sight) operation
- No long distance command and control links
- Flight over populated area at altitude of 1,200 m, 2 hour flight including 1 hour stay over the power plant
- Airspace segregated by civil aviation authority
- Safe and regular operation technologies are required

IV. UAS Traffic Management Study

Background: more sUAS in recent disaster, now

Heavy rain fall and landslide at Hiroshima, 2014[1)]

Kumamoto earthquake 2016[2)]

Media drone “chased” disaster relief helicopter flying low altitude[3)]

Geographical Survey

Infrastructure damage assessment by company

- Small UAS are now more popular and many VLOS operations
- Small UAS were flown by governmental institute, universities, companies, NPOs, news medias
- Conflict resolution will be required in future disaster

1) https://blogs.yahoo.co.jp/y294maself/34523293.html
2) https://news.yahoo.co.jp/story/146
3) https://weathernews.jp/soramagazine/201705/08/

IV. UAS Traffic Management Study

UTM concept proposed by NASA

NASA UTM
https://utm.arc.nasa.gov/documents.shtml

Global UTM Association

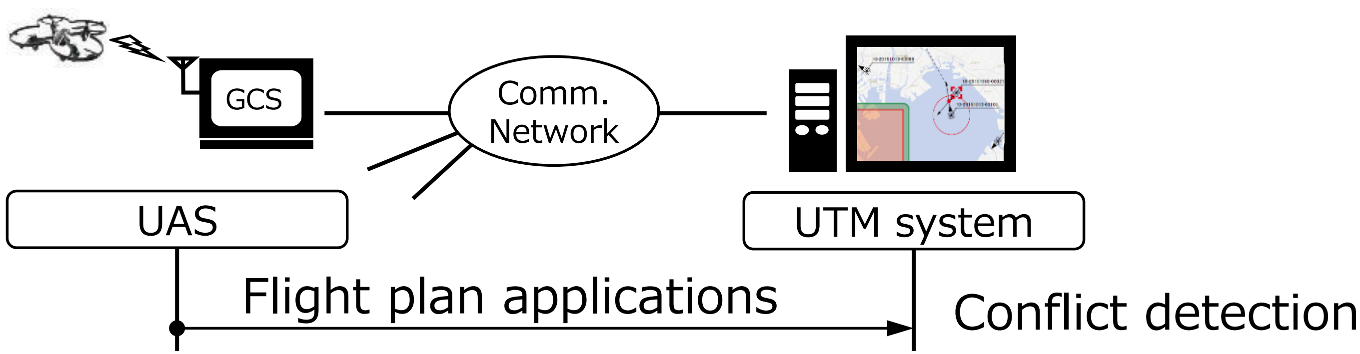
ICAO

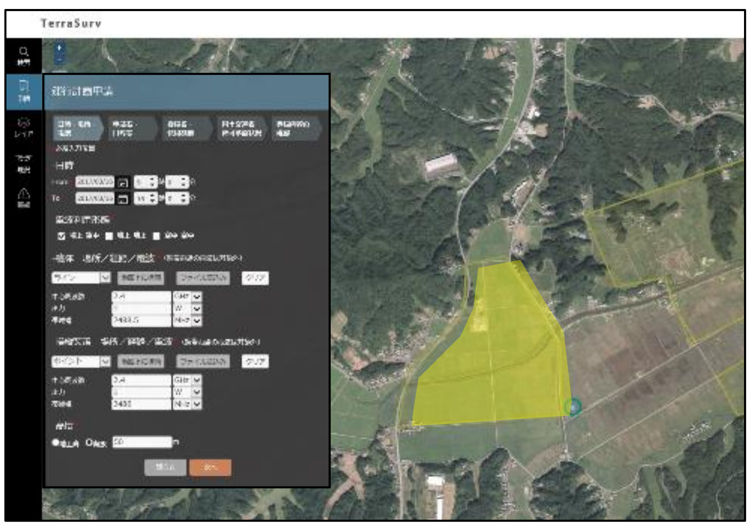
*"Currently, there is no established **infrastructure to enable and safely manage the widespread use of low-altitude airspace and UAS operations**, regardless of the type of UAS. A UAS traffic management (UTM) system for low-altitude airspace may be needed, perhaps leveraging concepts from the system of roads, lanes, stop signs, rules and lights that govern vehicles on the ground today, whether the vehicles are driven by humans or are automated."*

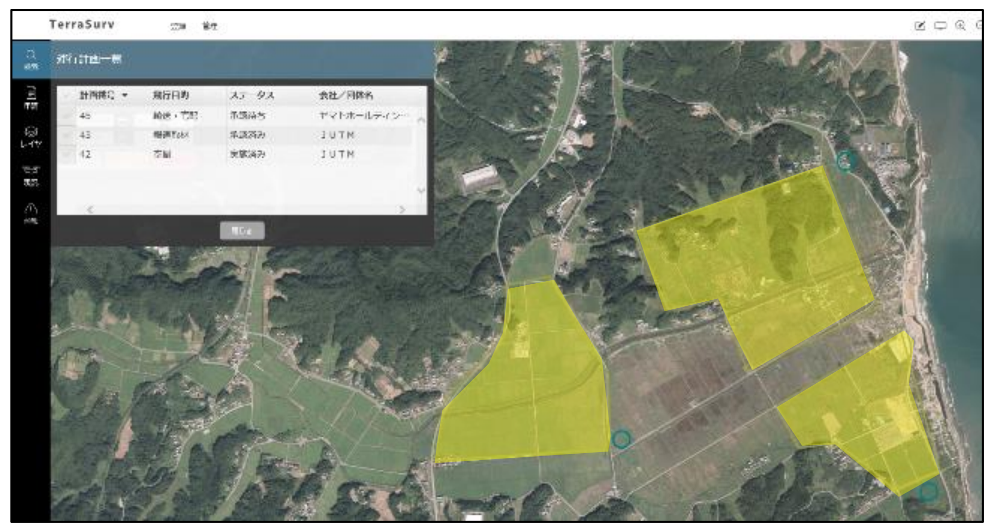
(cited from NASA UTM website)

IV. UAS Traffic Management Study

UTM basic research and experiment in Japan







IV. UAS Traffic Management Study

Flight performance study: gust tolerance of small UAS

Gusty wind ??? [1)]

- Wind tolerance is one of the most important technical challenges for the practical use of drones
  - sUAS's relatively light weight and low-altitude operation
  - Too high "drone user's requirement" of position control accuracy even in gusty wind
- For beyond visual line of sight (BVLOS) operations, guidance accuracy degradation due to the existence of gust wind is an important factor

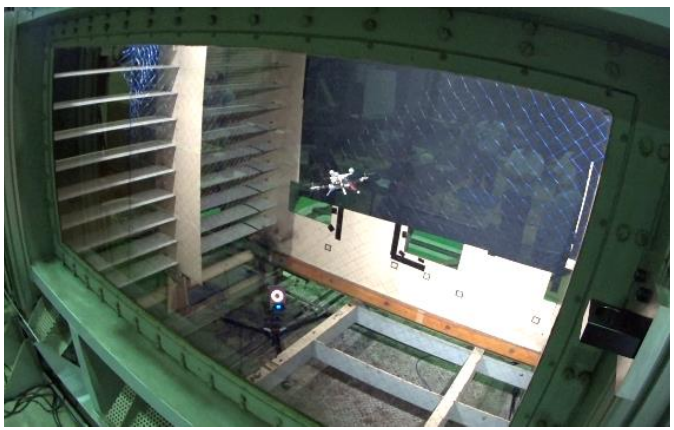
1) http://www.triplem.com.au/melbourne/news/blog/2013/7/wind-to-smash-victoria/

IV. UAS Traffic Management Study

Gust wind tunnel flight for direct gust response evaluation

2x2 m low speed WT with gust generator

Using a gust wind tunnel facilities and a motion capture based precise flight control system, direct gust tolerance performance evaluation method was constructed.



Actual flight in gust wind tunnel

Precise navigation and guidance using a motion capture technology

Advantages:

- ✓ Free flight without any aerodynamic interference
- ✓ Reproducibility and quantitativeness

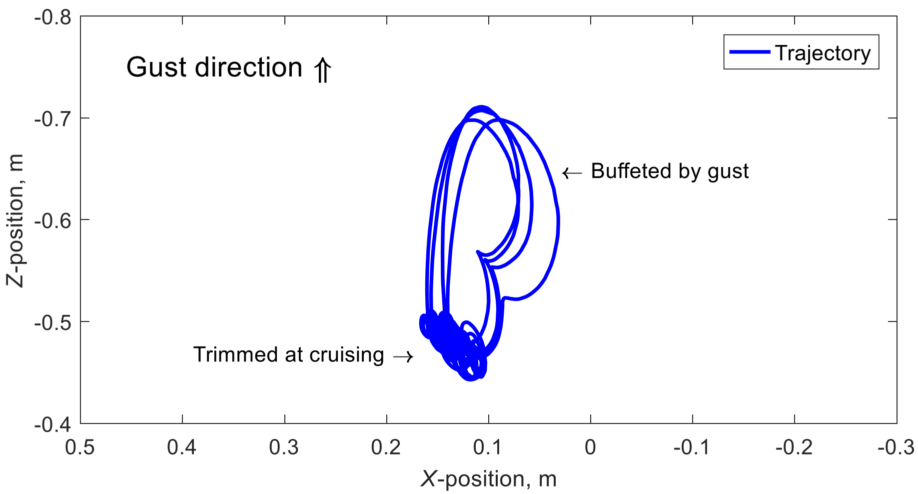
Limitations:

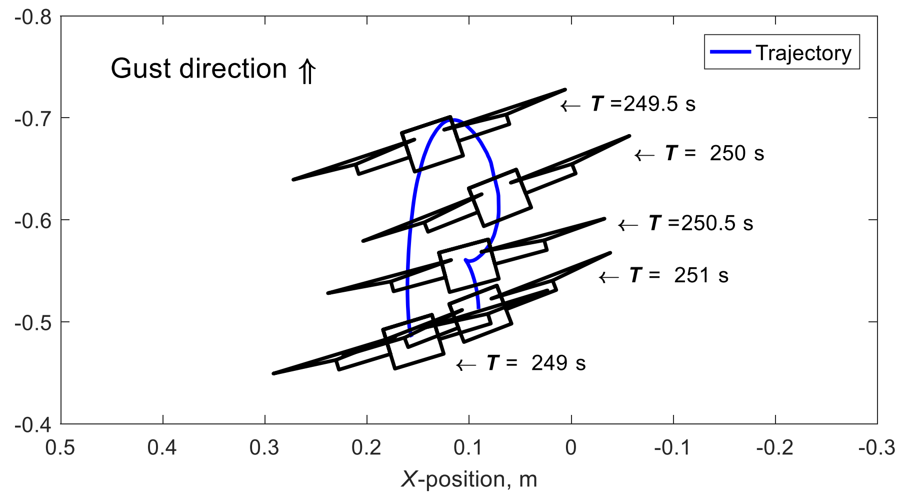
- ✓ The wind tunnel can generate only brown-up and down gust, however, cross wind gust is also important

IV. UAS Traffic Management Study

"1-cos Type" Isolated Gust Response (1Hz, 10 m/s)

Video

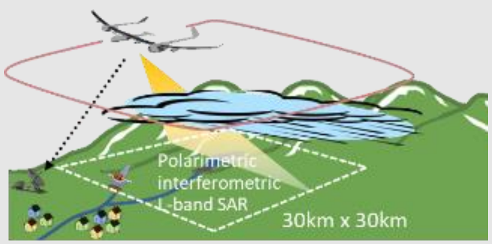




- Reproducible gust response trajectories were obtained
- Pitch attitude was not much affected by the blown-up gust, which is different from those of head or tail-wind gust response in another experiment

Summary

Disaster Risk Reduction using UAS



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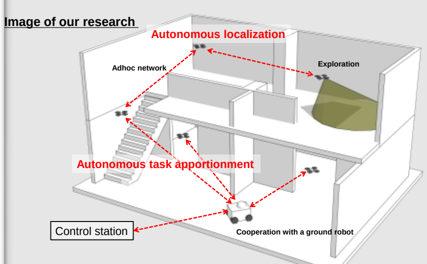

III. Multiple MAV corporative mission capability (2012-)

IV. UAS traffic management and flight performance (2015-)

Thank you for your kind attention!

Please do not hesitate to visit Japan!!

Daisuke Kubo

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