FEATHER project in JAXA and toward future electric aircraft

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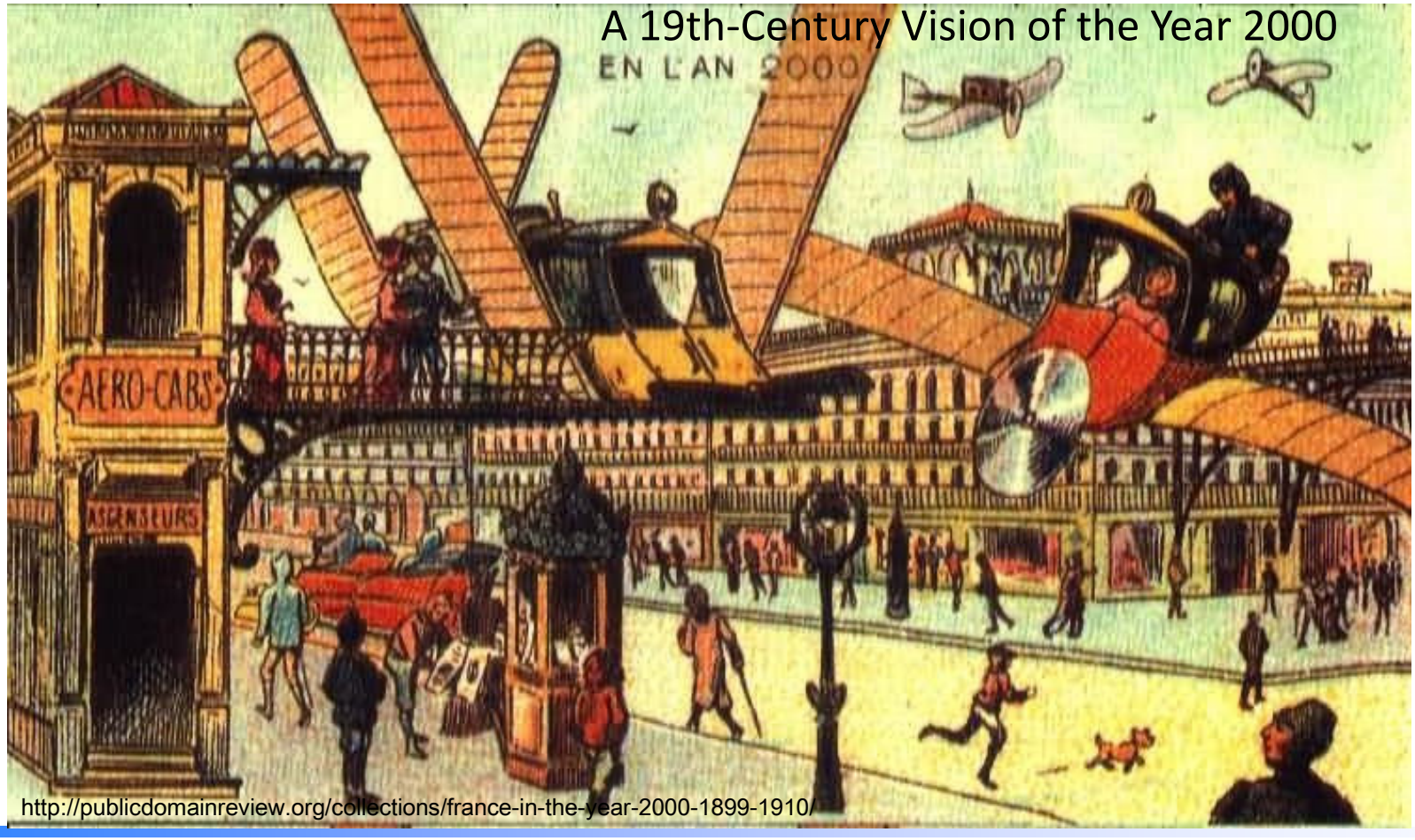
Outline

1. Future Vision and Issues
2. FEATHER project
3. Toward future electric aircraft

1. 1 Future vision

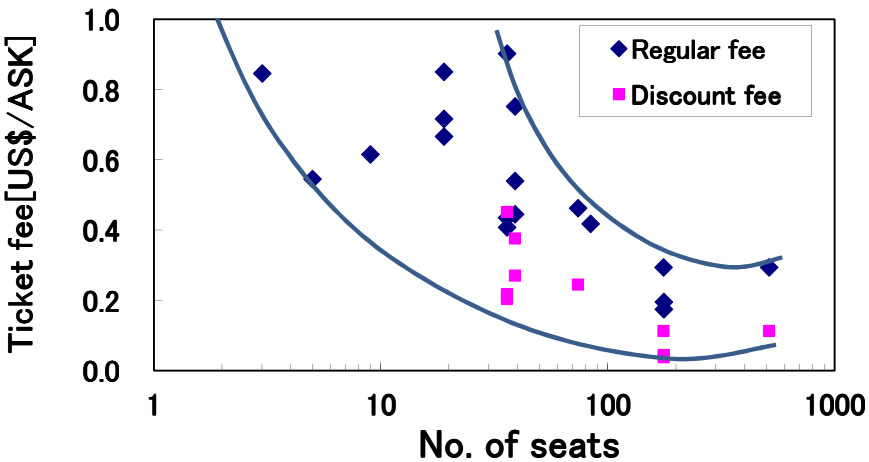


A 19th-Century Vision of the Year 2000

http://publicdomainreview.org/collections/france-in-the-year-2000-1899-1910/

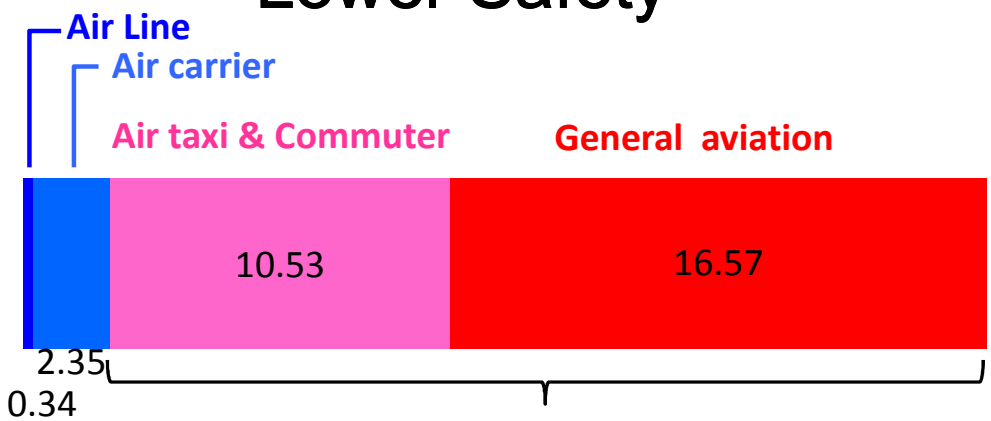
1. 2 Problems of Small Aircraft

Higher Cost



Unit ticket fees for domestic flights (in JAPAN, 2014)

Lower Safety



The fatal accident rate of small aircraft is about **10X higher** than that of large aircraft

Number of fatal accidents per 1 million flight time (average during 1982-1999 in USA)

Source: NTSB Aviation Accident Database

1.3 Major issues and solution

Goal

Popularization of General Aviation

PAV, AirTaxi, ODM

Issues

Reduction of operating cost

Current：3～5X higher than airliner

Reduction of fatal accidents

Current：10X higher than airliner

Solution

Electric aircraft technologies

JAXA

utilization

Potential strength of Japanese industries
(electric motor, battery, power device,...)

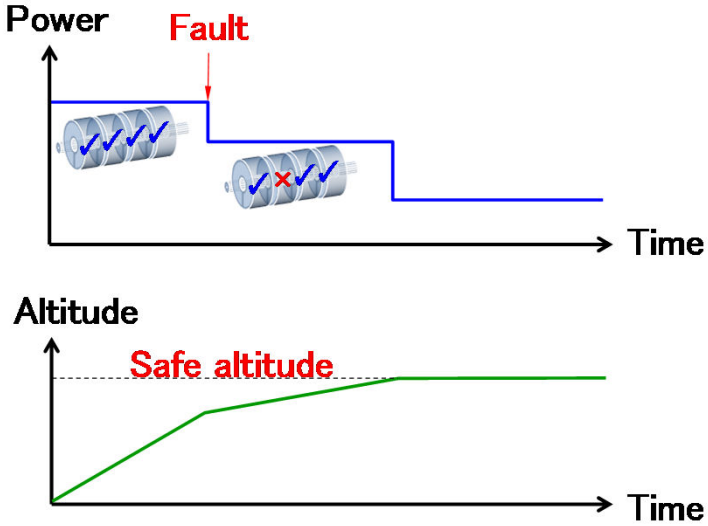
Outline

1. Future Vision and Issues
2. FEATHER project
3. Toward future electric aircraft

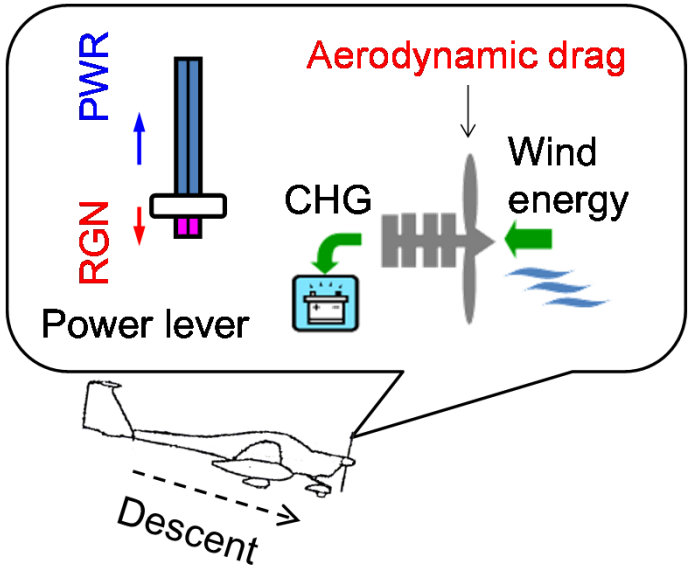
2.1 Outline of FEATHER project

Mission
- Development of JAXA's unique electric propulsion systems

FY2012	FY2013	FY2014
Design	Fabrication	Integration and flight test



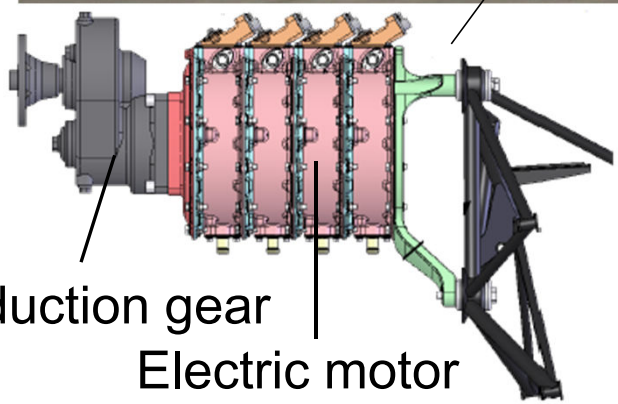
1. Multiplexed motor

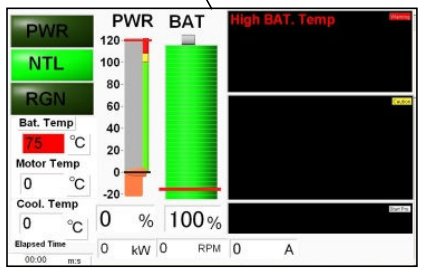


2. Regenerative air brake

2.2 Overview of the demonstrator

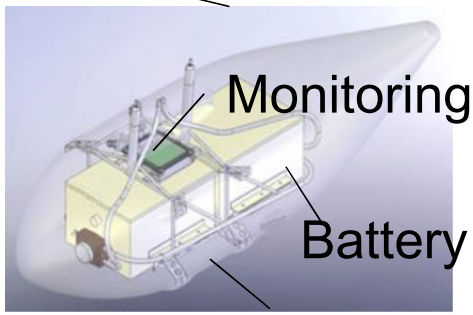
Original aircraft: Diamond aircraft type HK36TTC-ECO





Display

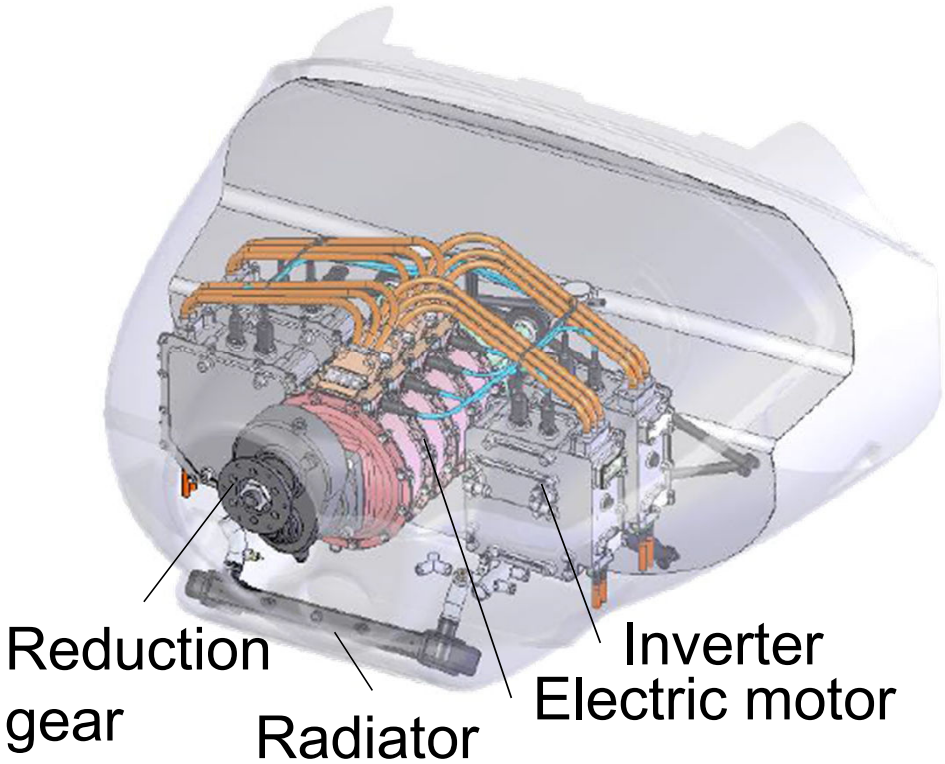
Power lever



Under wing container

①Multiplexed motor **②Pilot interface** **③Li-ion battery**

2.3 Electric propulsion system

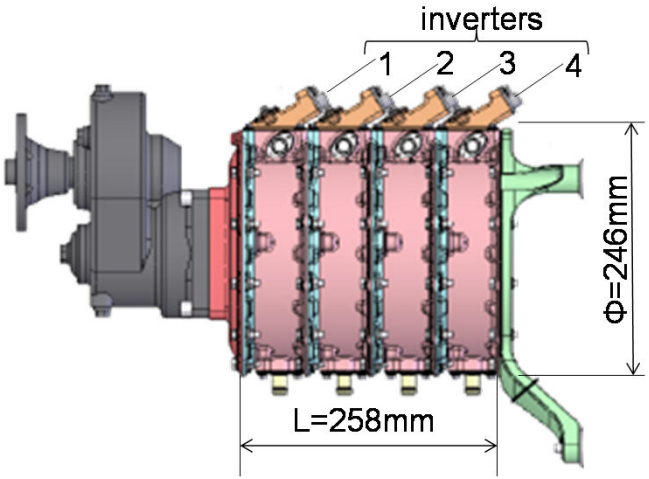


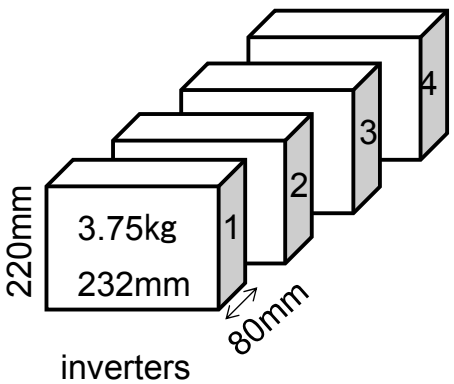
Electric propulsion system

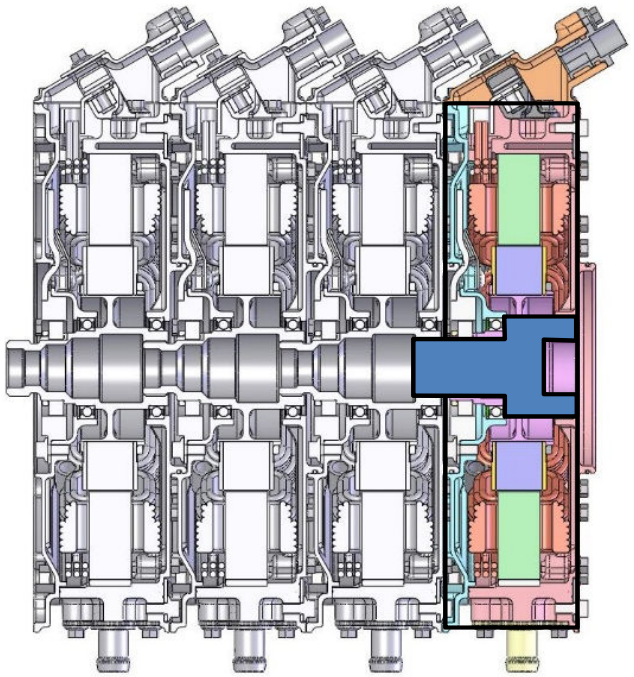
2.4 Specifications

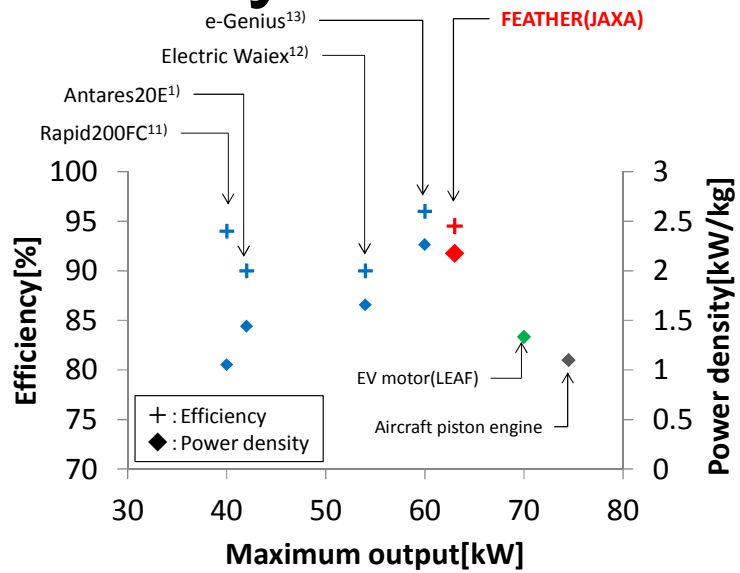
Specifications	
Wing span	16.33m
Take-off weight at the flight test	800kg
Crew member	1 person
Types of electric motor and inverter	Permanent magnet type synchronous motor (three-phase) and IGBT inverter
Motor control method	FOC (Field-oriented control)
Maximum total shaft power (at RPM)	60kW (2.5min. at 6586RPM), 63kW(proven at flight)
Type of power source	Lithium-ion battery (32 cells in series)
System voltage (open circuit at 100%SOC) and Current	128V, 750A

2.5 Multiplexed electric motor system







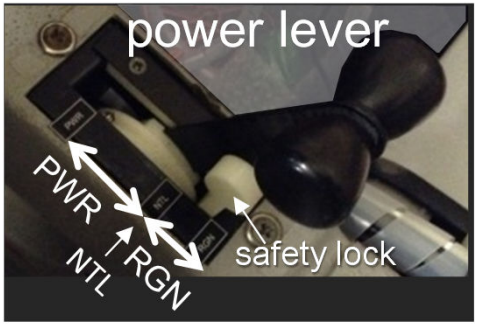


Characteristics

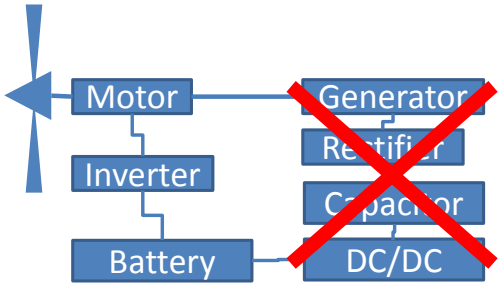
- ✓ Compact
- ✓ Light weight(2.17kW/kg)
- ✓ High efficiency(95%)
- ✓ High strength of structure

2.6 Regenerative air brake system(1/4)

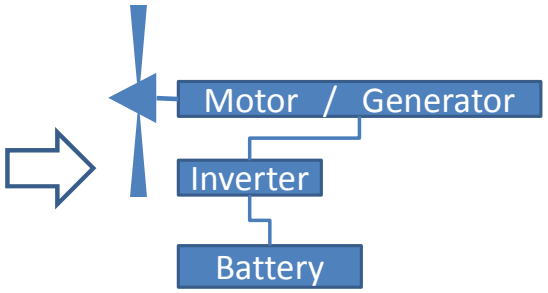
Characteristic features	1. Augmentation of descent rate by only pulling the power lever w/o conventional air brake 2. No weight penalty based on the field-oriented control method 3. Maximization of the regenerative electricity for variable air speeds



Power lever



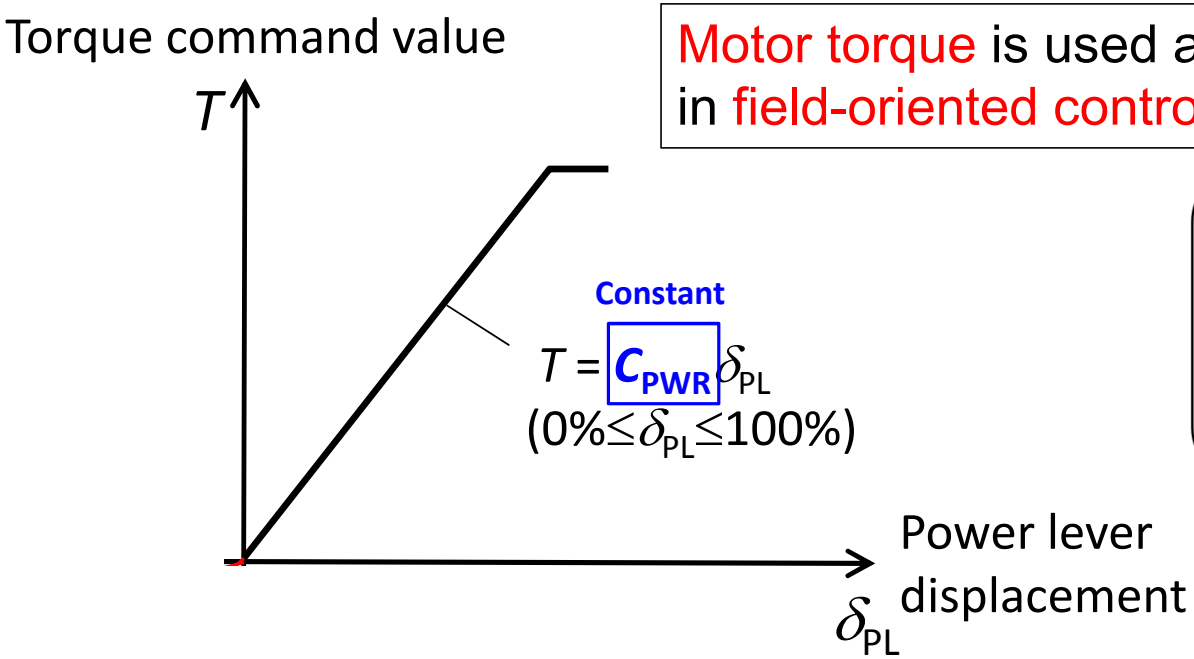
Conventional

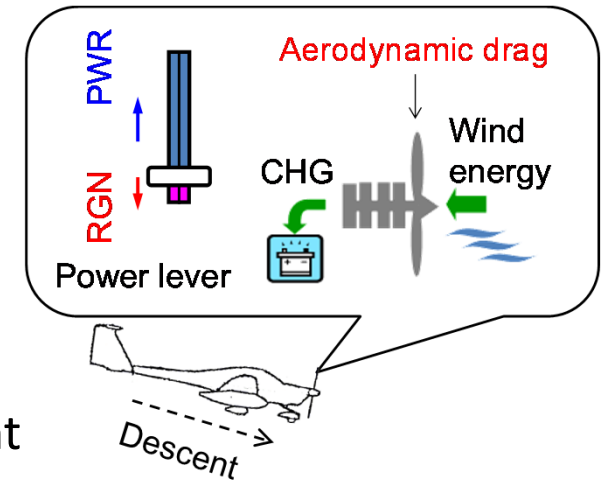


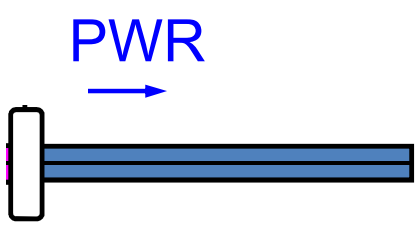
Field-oriented control

2.6 Regenerative air brake system(2/4)

Motor torque is used as a command value in field-oriented control method





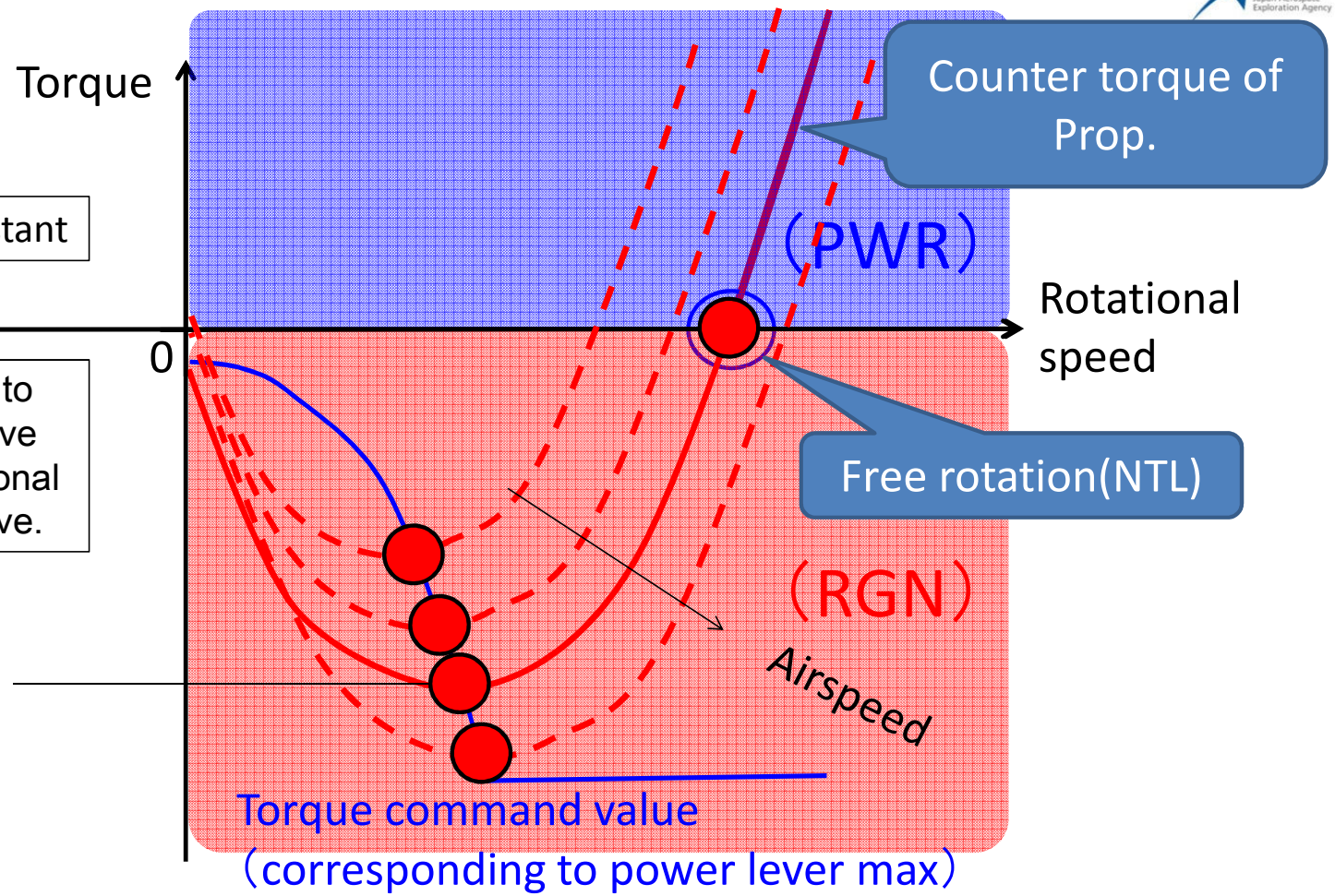


2.6 Regenerative air brake system(3/4)

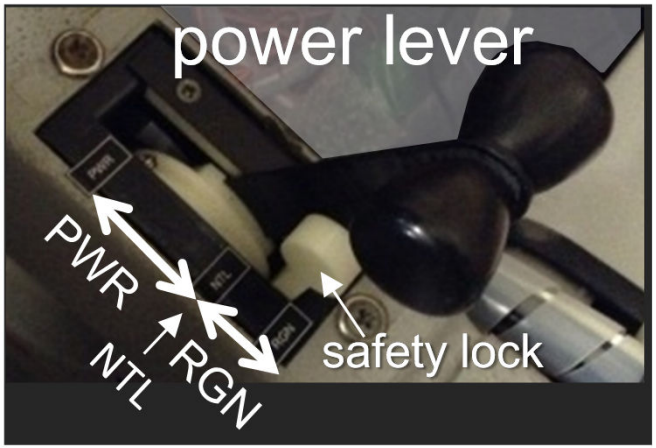
✓ Pitch angle of a blade = constant

The torque command value has to intersect with counter torque curve of propeller, otherwise the rotational number becomes zero or negative.

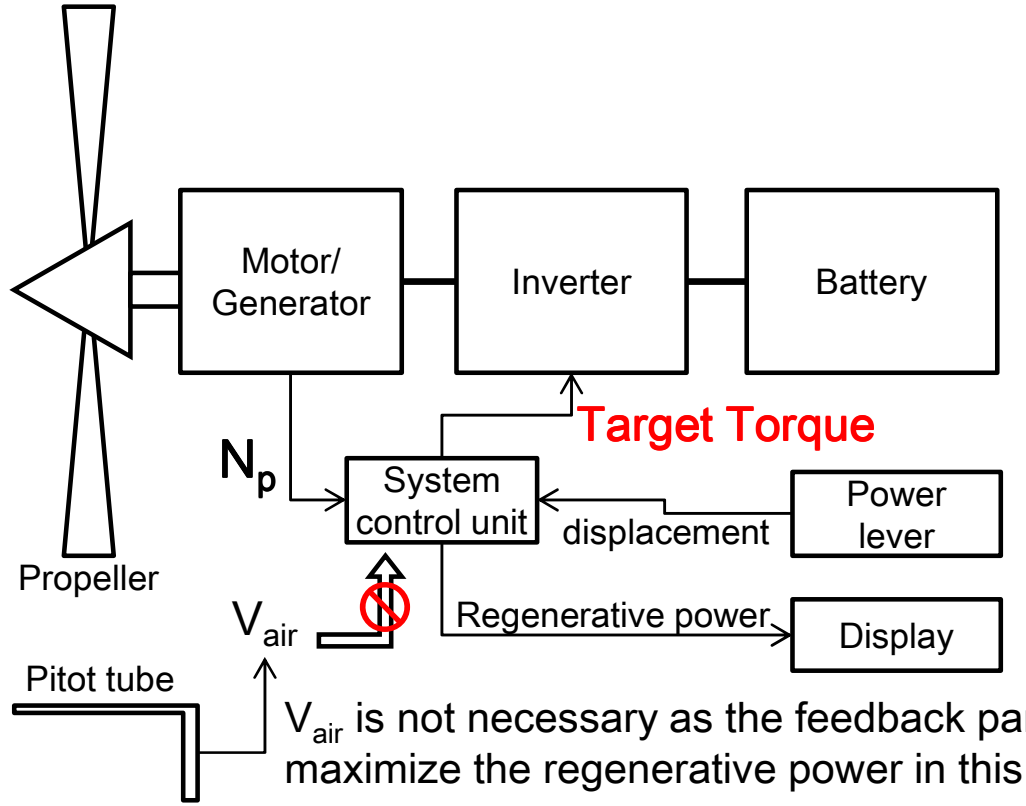
Maximization of the regenerative electricity



2.6 Regenerative air brake system(4/4)



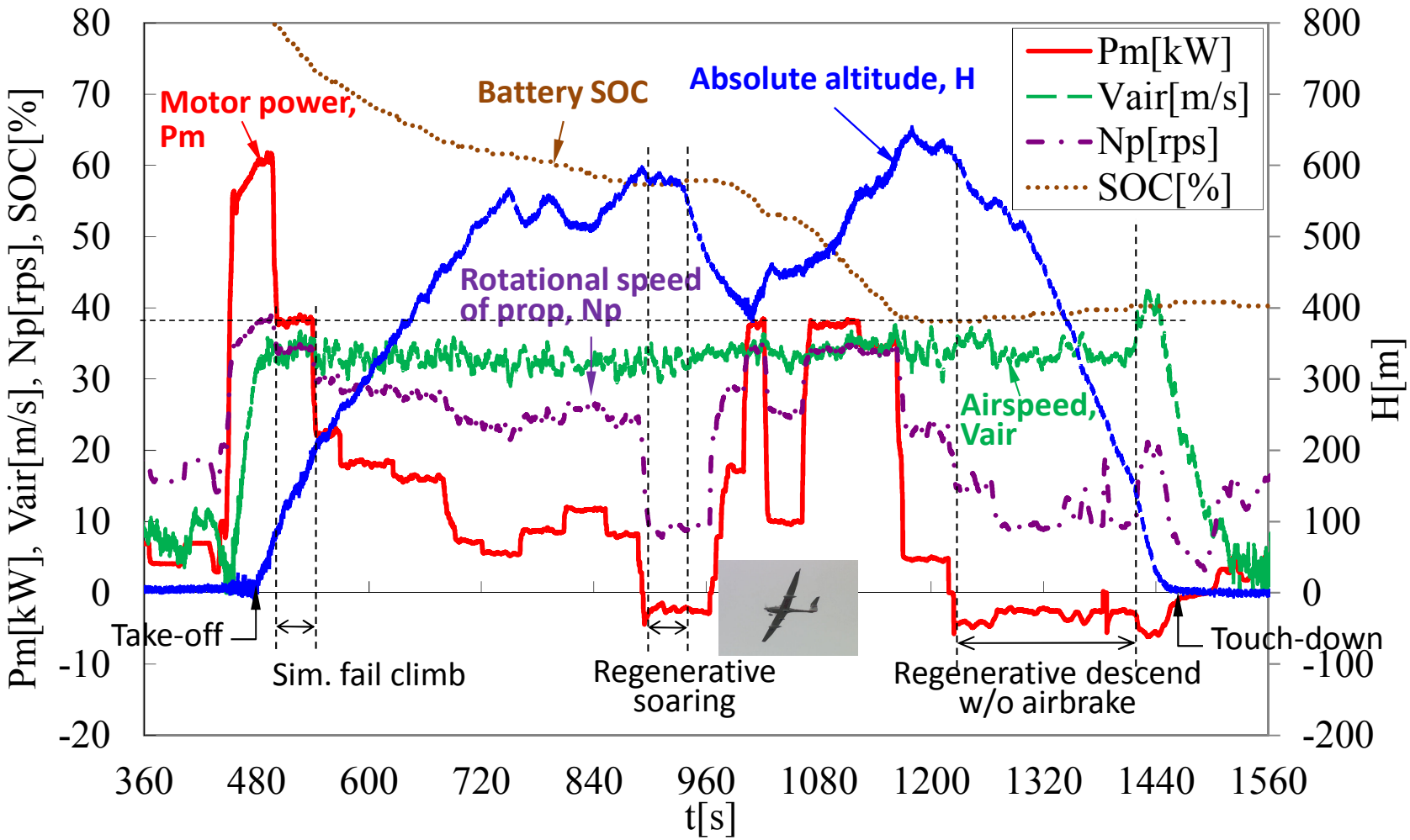
Specially designed power lever to facilitate the control of descent rate and regeneration



V_{air} is not necessary as the feedback parameter to maximize the regenerative power in this system.

Block diagram of the regenerative air brake system

航空機用電動推進システム技術の飛行実証

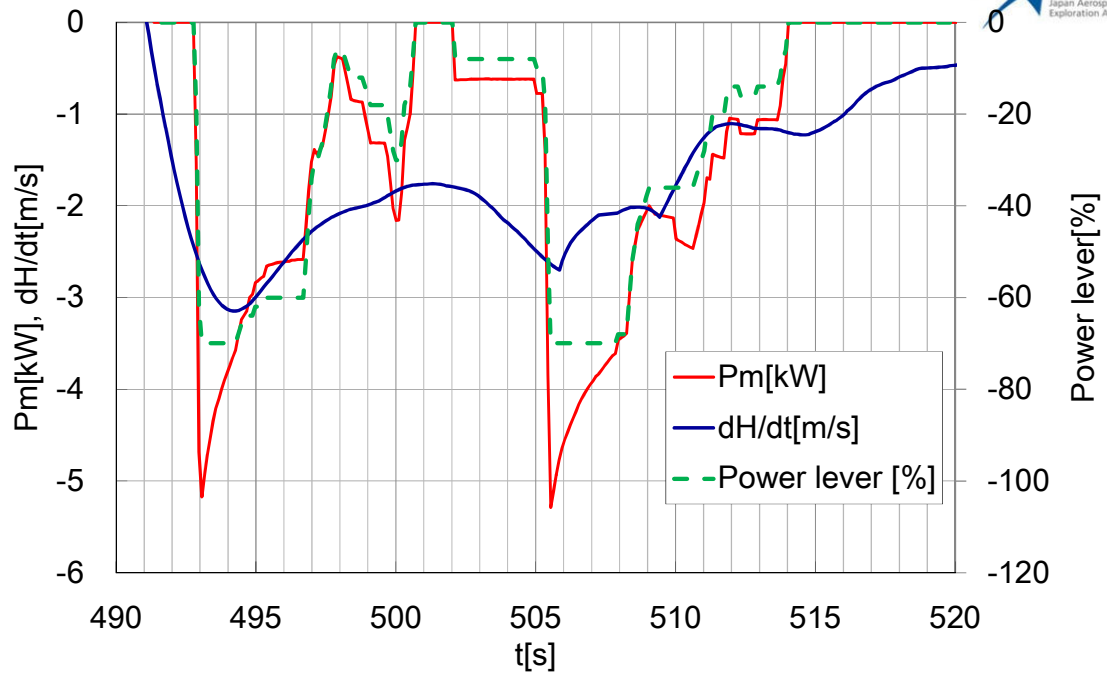


An example of flight test data

2.7 Flight demonstration

Descent by using the conventional airbrake

Descent by using the "regenerative airbrake system"



Correlation of the power lever displacement, regenerative power and consequent descent rate, dH/dt during descent by using regenerative airbrake system

Outline

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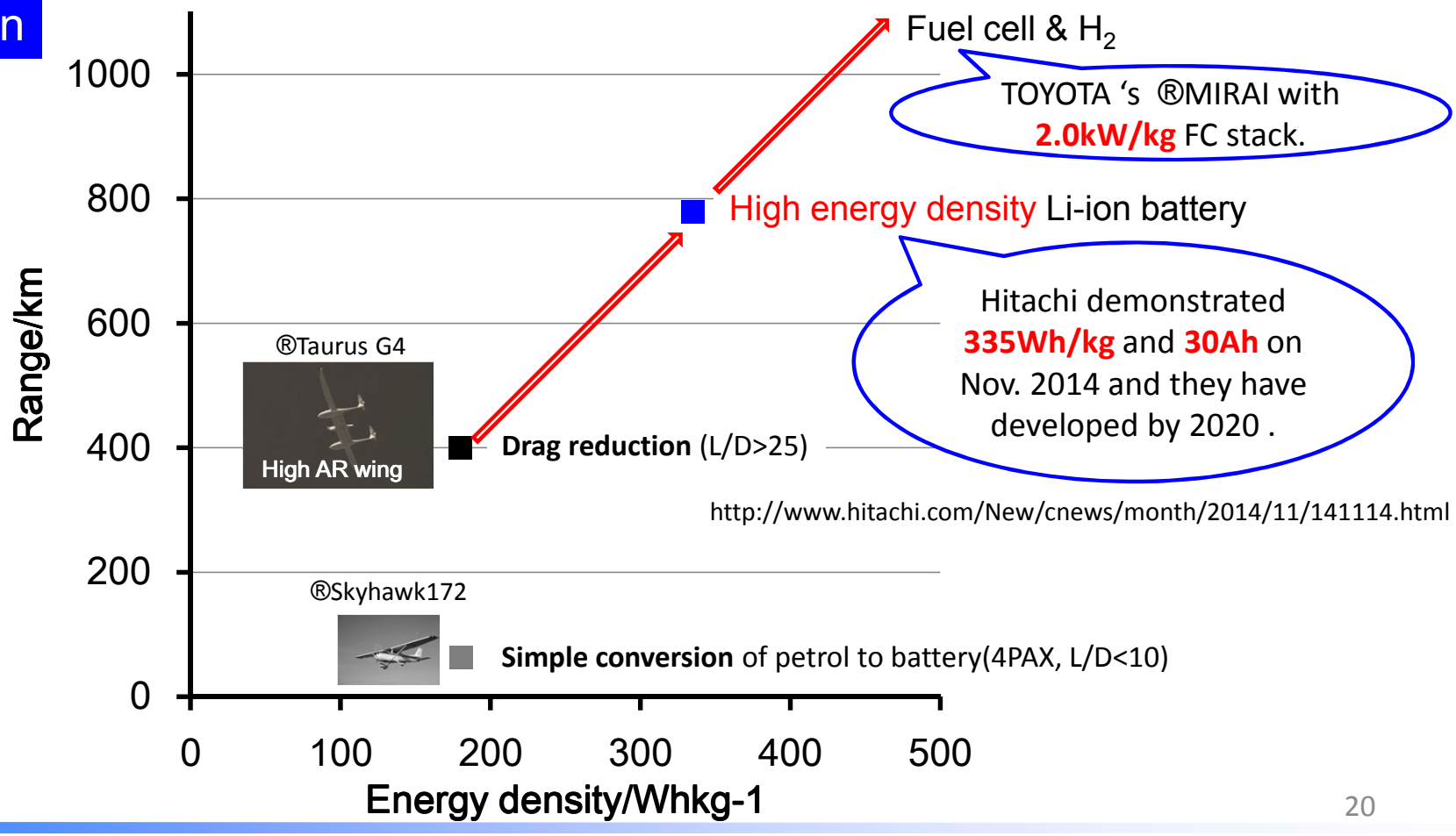
3. Toward future electric aircraft

3. Toward future electric aircraft

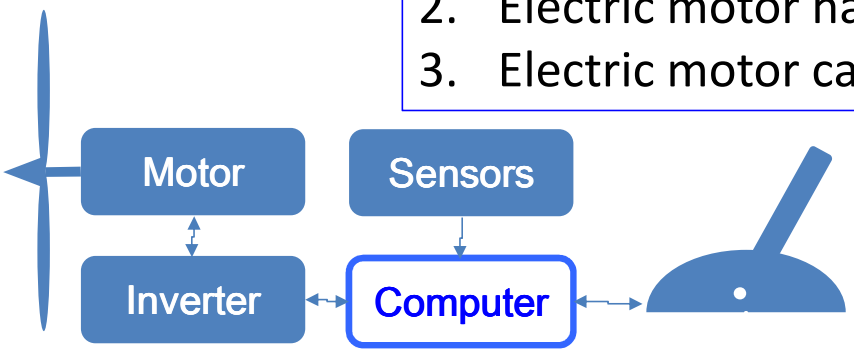
Range Extension



3. Toward future electric aircraft

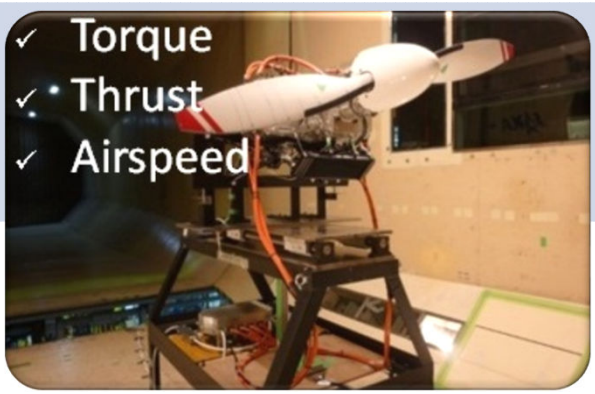
Automatization

1. Electric propulsion system have a high affinity for automatization.
2. Electric motor have a high response performance.
3. Electric motor can be flexibly arranged on a wing or a fuselage.

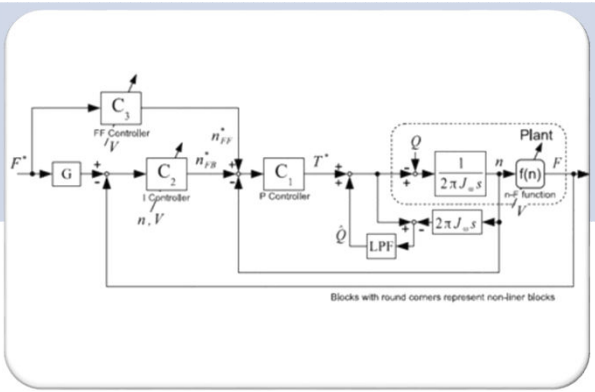


Power by wire Key technology

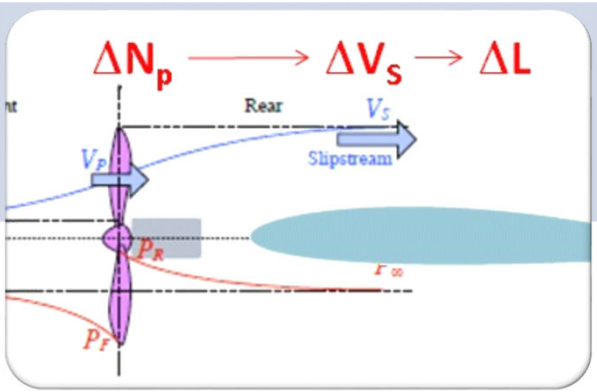
Collaborative work



Sensing Actuator



Control Algorithm



Alternative S&C

Thank you
http://www.aero.jaxa.jp/eng/research/frontier/feather/
http://hflab.k.u-tokyo.ac.jp/index.html

1. Backgrounds & Objectives

Long-term research toward zero-emission aircraft

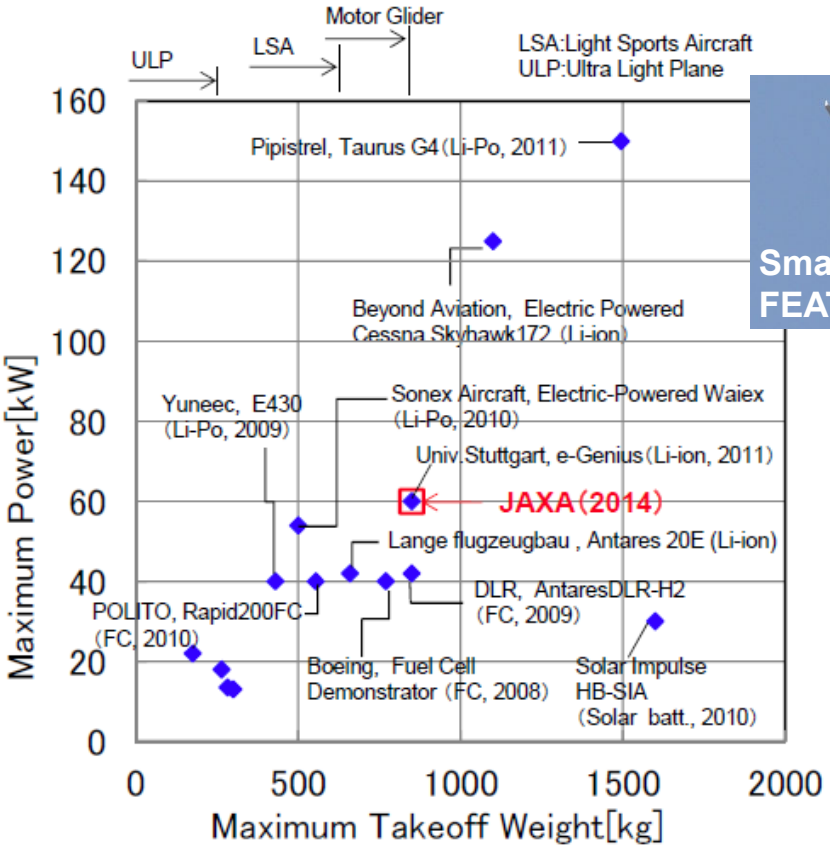
Electric and hybrid propulsion system for aircraft

1. **FEATHER project**
2. **Concept study of fuel cell–gas turbine hybrid aircraft**

⇕ collaborative work

東京大学 THE UNIVERSITY OF TOKYO

Target and mission of FEATHER



<u>Mission of FEATHER project</u>

- To get flight permission from JCAB as the first case of electric manned flight in Japan
- Development of JAXA's unique electric propulsion system
- Flight validation of the new functions and system performance

http://www.aero.jaxa.jp/publication/pamphlets/pdf/apg2012-kouen03.pdf

Mile stones

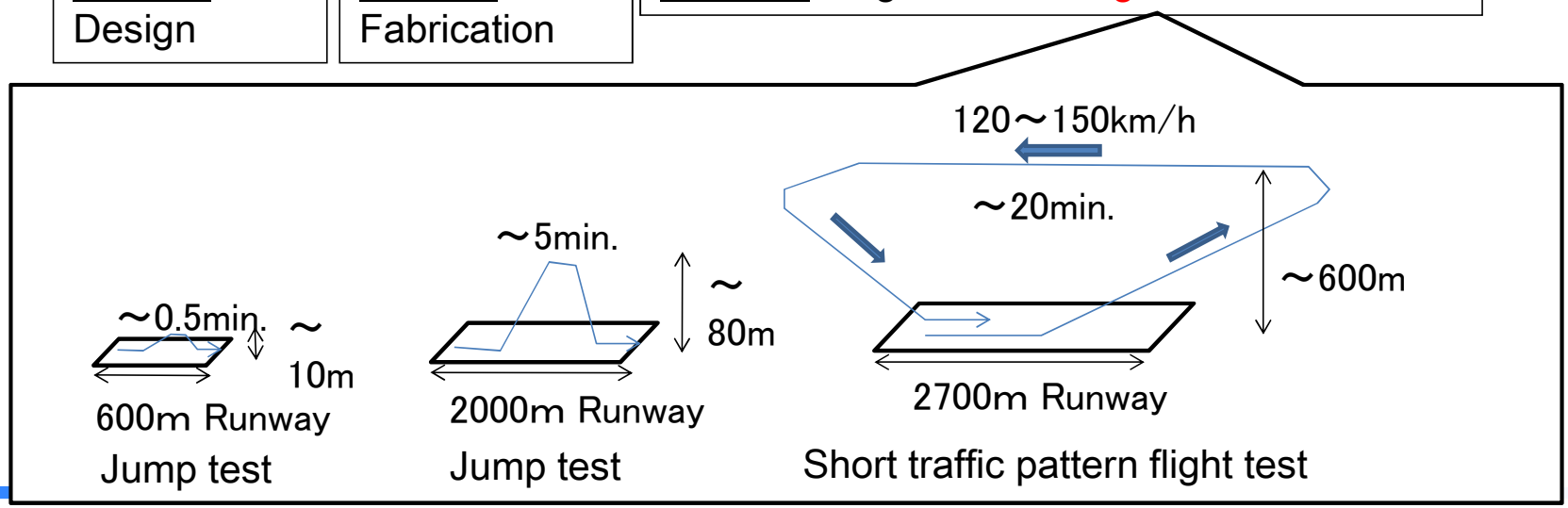
2012-2013	2014			2015
June	March	July	November	February

- June: Start
- March: Complete of electric propulsion system
- July: Integration
- November: Approval for flight test
- February: Approval for flight test

Maiden flight

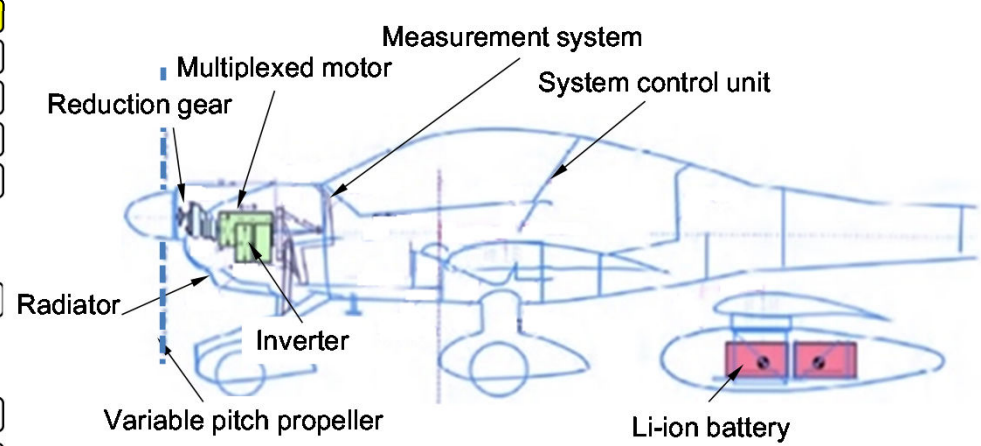
Final flight

FY2012 Design	FY2013 Fabrication	FY2014 Integration and flight test



2. Systems

- A) Electric motor-glider system
  - A1) Electric propulsion system
    - A1-1) Driving system
      - Multiplexed motor
      - Inverter
      - Radiator & Pump
      - Reduction gear
      - Propeller
    - A1-2) Power source
      - Li-ion battery
    - A1-3) Pilot interface
      - Power lever
      - Display
    - A1-4) Management system
      - System control unit
  - A2) Measurement system
  - A3) Airframe system
  - A4) Charging system

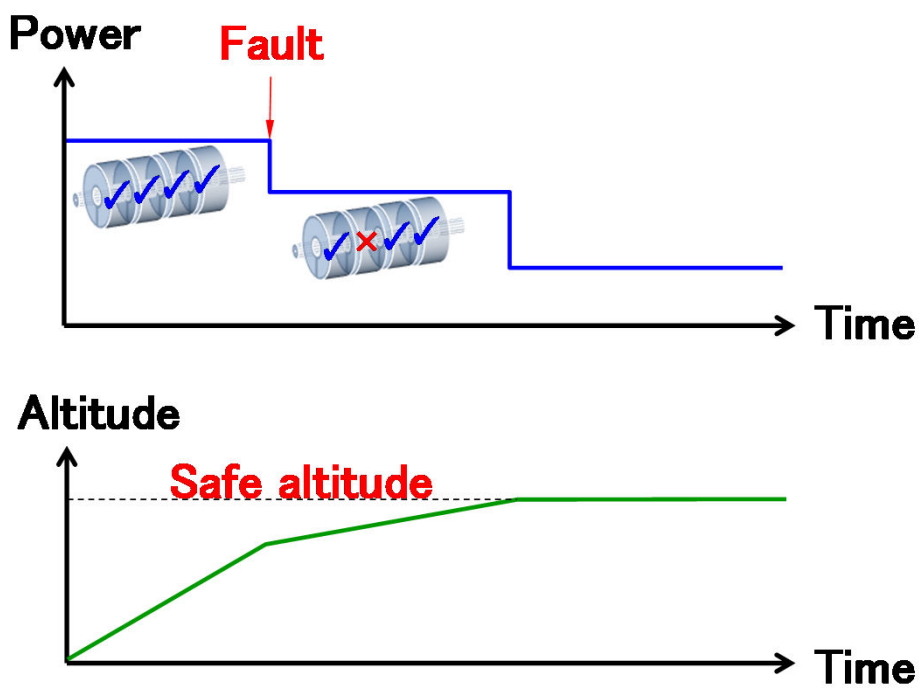


Electric motor-glider system
(Flight demonstrator)

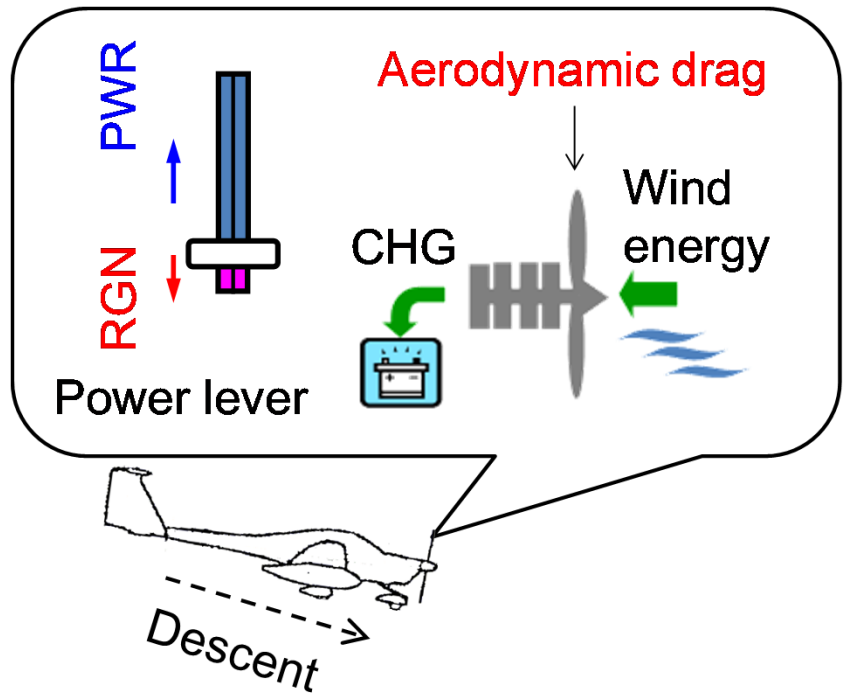
System configuration

3. Concepts

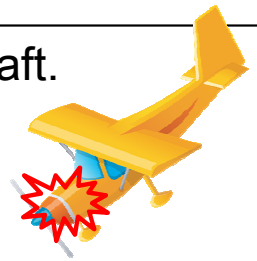
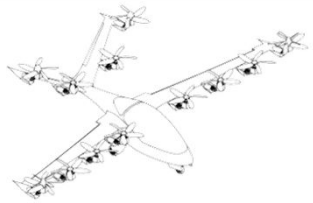
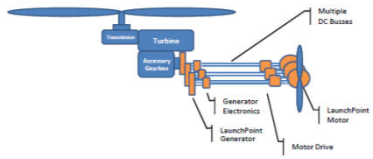
1. Multiplexed motor



2. Regenerative air brake

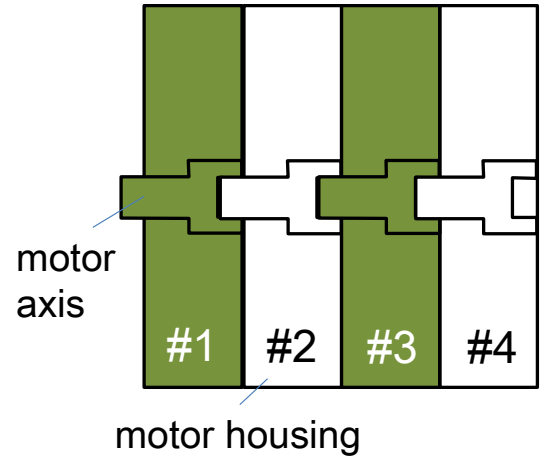


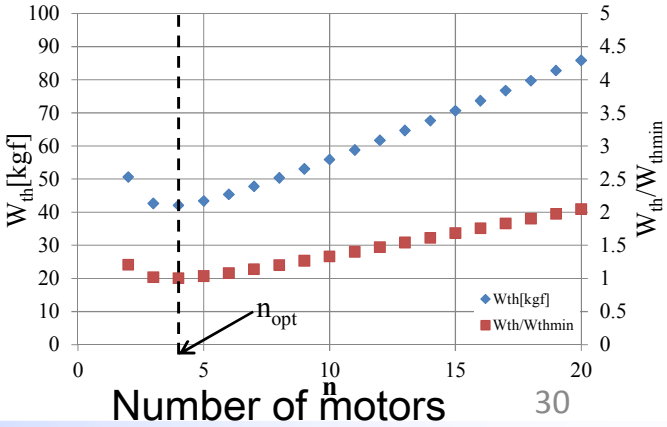
3.1 Multiplexed electric motor system(1/3)

Our motivations	1. Avoidance of "loss of engine power" for single piston engine aircraft. 2. Redundancy of electric motors.	
Other researches	1. Distributed motors and fans for VTOL (Alex M. Stoll et al. of Joby Aviation, 14th AIAA Aviation Technology, Integration and Operations Conference 2014, AIAA2014-2407) 2. Electric Propulsion for Vertical Flight (Michael Ricci of LaunchPoint Technologies; AHS Transformative Vertical Flight Workshop 2014, Arlington, VA)	 Multiple Lane Design 
Our selection of approach	Putting multiplexed motor on a propeller shaft	

3.1 Multiplexed electric motor system(2/3)

Technical issues for us	1. Reduction of the size and weight 2. Optimization of the number of motors 3. Isolation of failures
Our solutions	1. Directly coupling with each motor (additional joint parts are unnecessary) 2. Quadruplex motor based on the trade-off analysis 3. Individual contactors

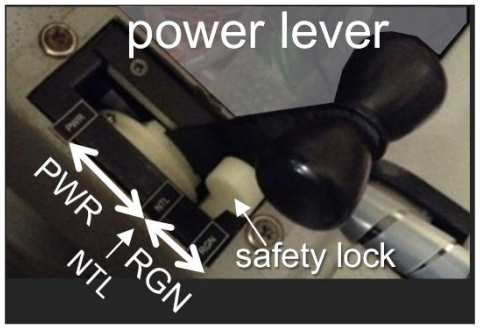
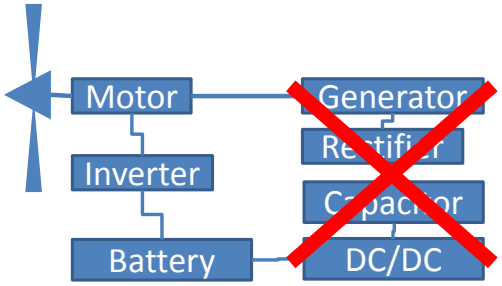
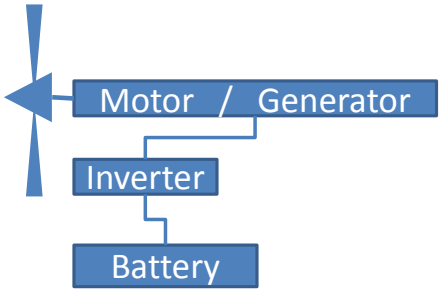




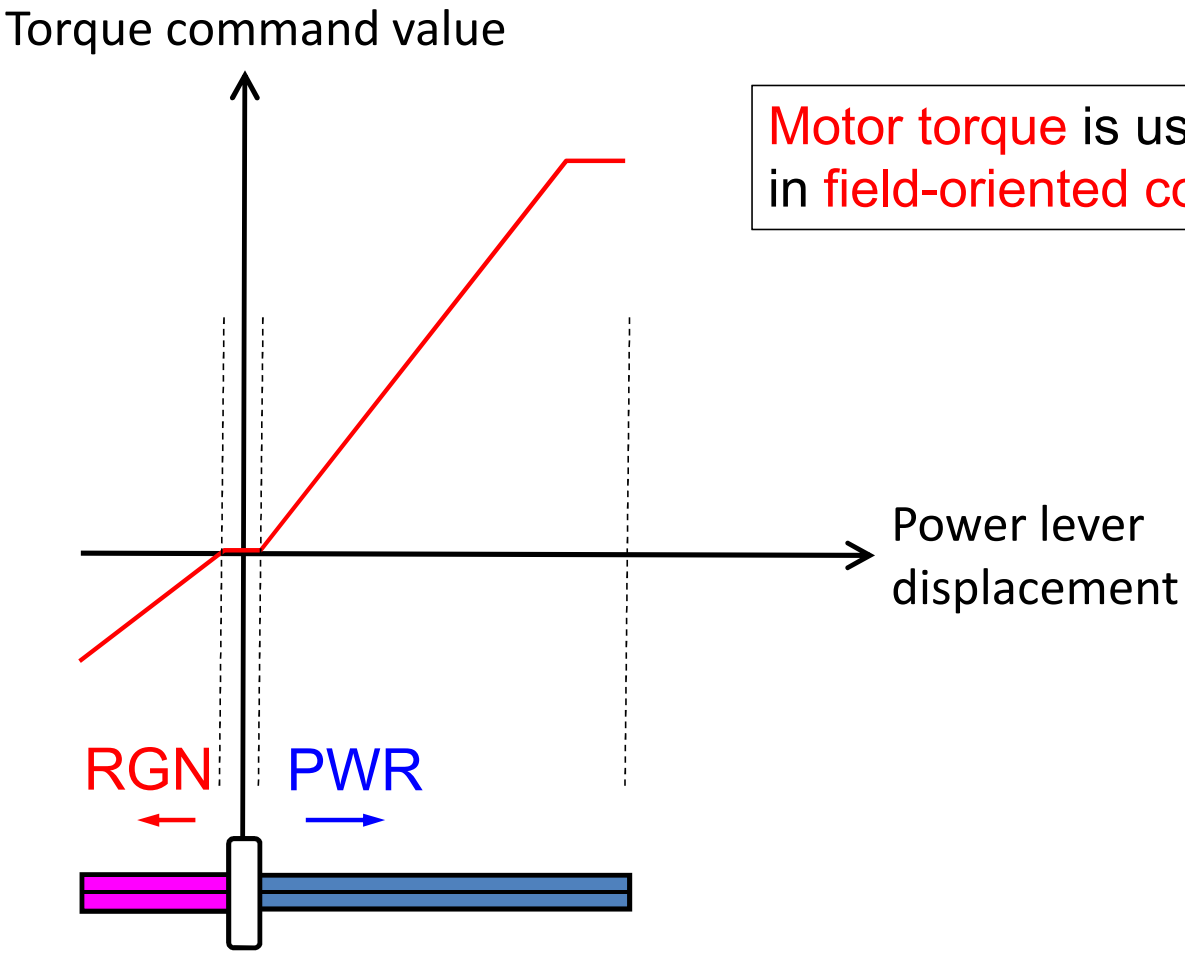
3.2 Regenerative air brake system(1/5)

Our motivations	1. Elimination of conventional systems by multifunctionality of electric motor. 2. Regeneration of electricity by electric motor.
Other researches	1. Feasibility study of regenerative soaring (J.Philip Barnes, Perican Aero Group, SAE Tech. Paper 2006-01-2422, 2006) 2. WATTsUP can recuperate 13% of energy on every approach and reduce the field length of landing(Pipistrel, Aircraft News,31 Mar 2015)
Our selection of approach	1. Utilization of aerodynamic drag on the prop. due to regeneration 2. Simultaneously harvesting a certain amount of energy

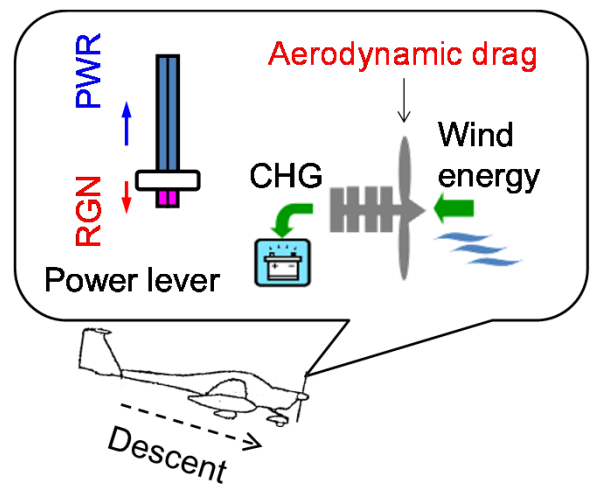
2.6 Regenerative air brake system(1/4)

Technical issues for us	1. Simplify the control of descent rate 2. Avoidance of weight penalty and hardware complexity 3. Maximization of the regenerative electricity
Our solutions	1. Augmentation of descent rate by pulling the power lever 2. The simplest system configuration based on the field-oriented control method 3. Formulation of control algorithm based on the aerodynamic features  Power lever  Conventional  Field-oriented control

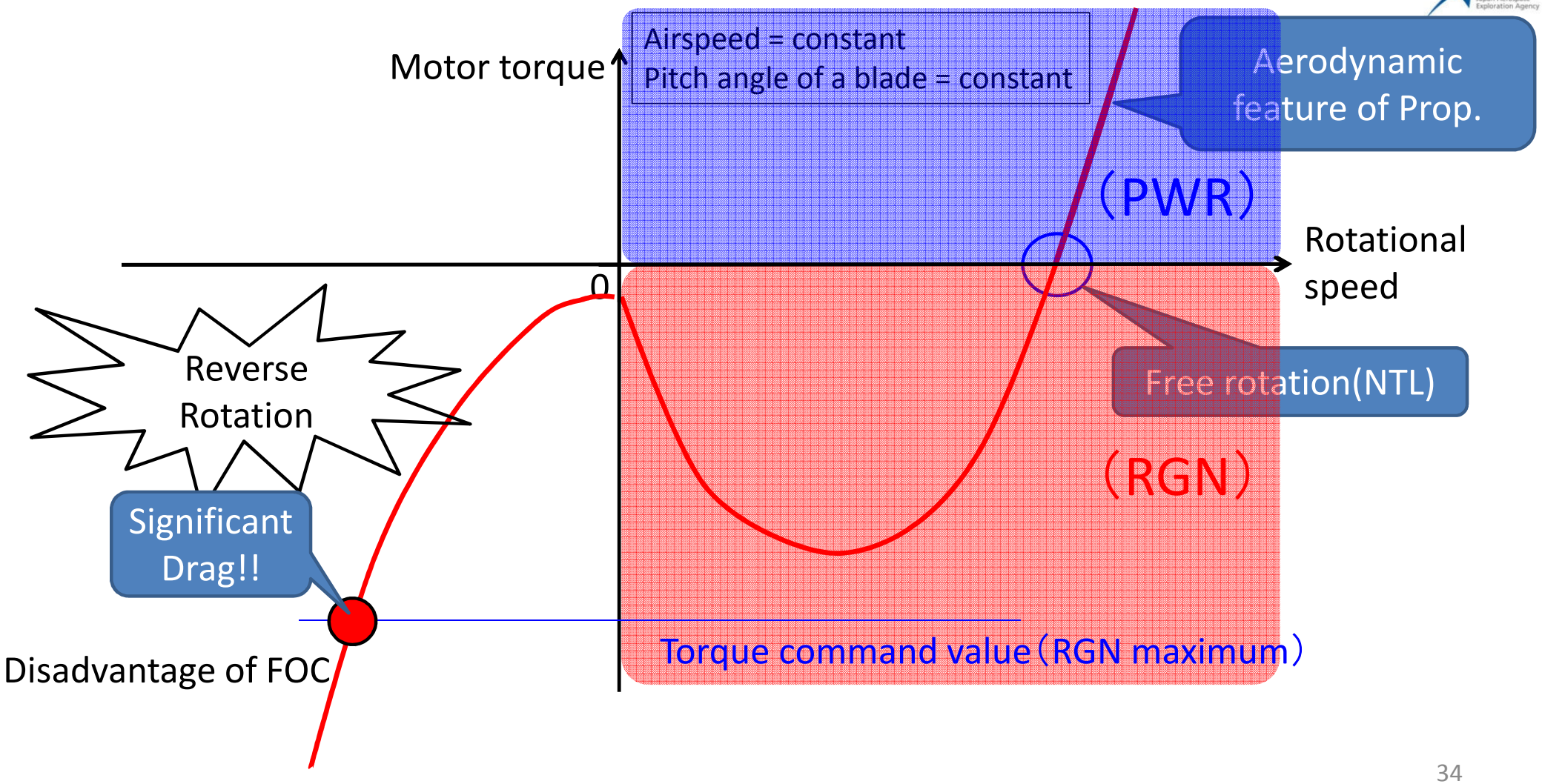
3.2 Regenerative air brake system(3/5)



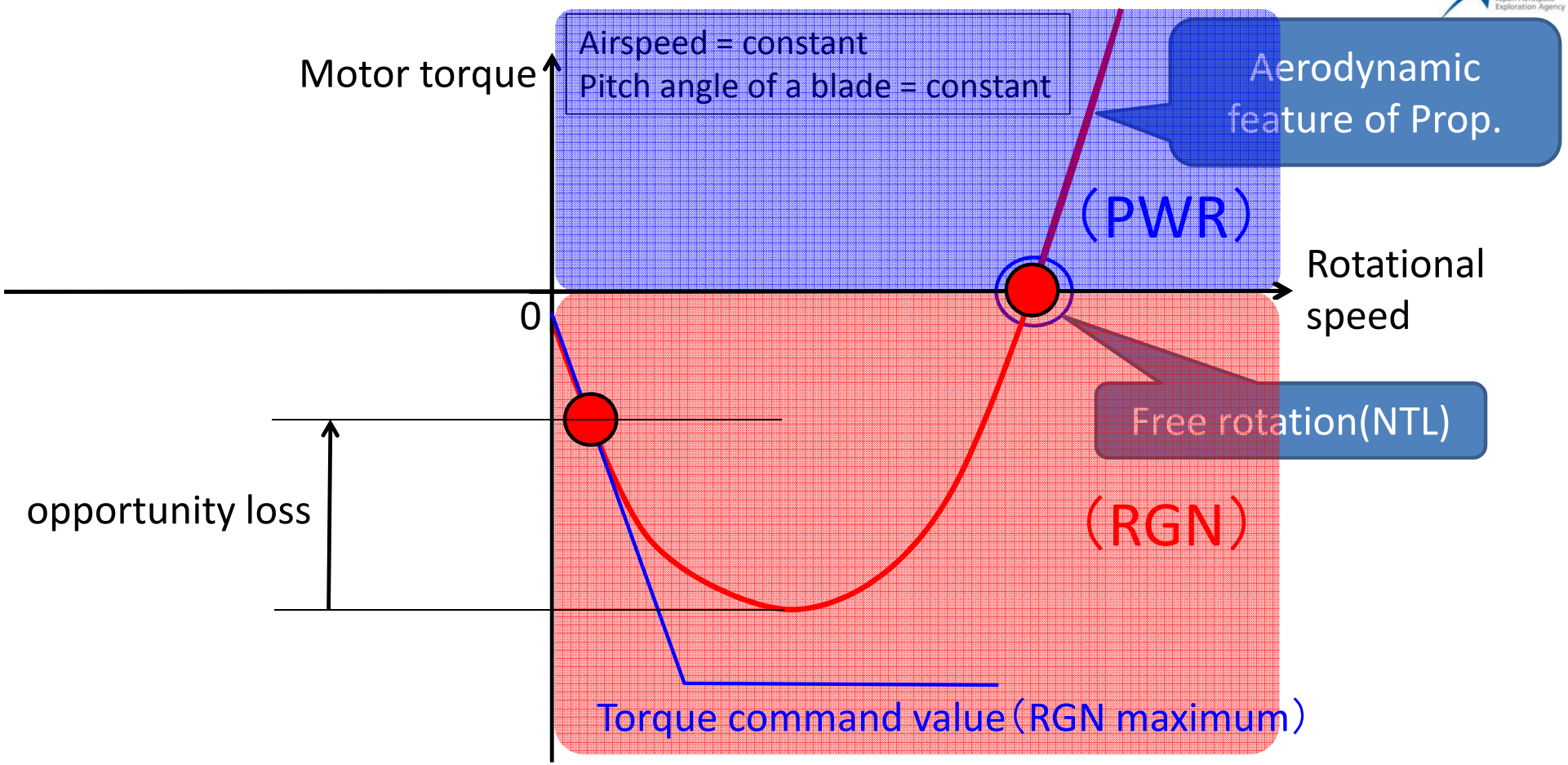
Motor torque is used as a command value in field-oriented control method



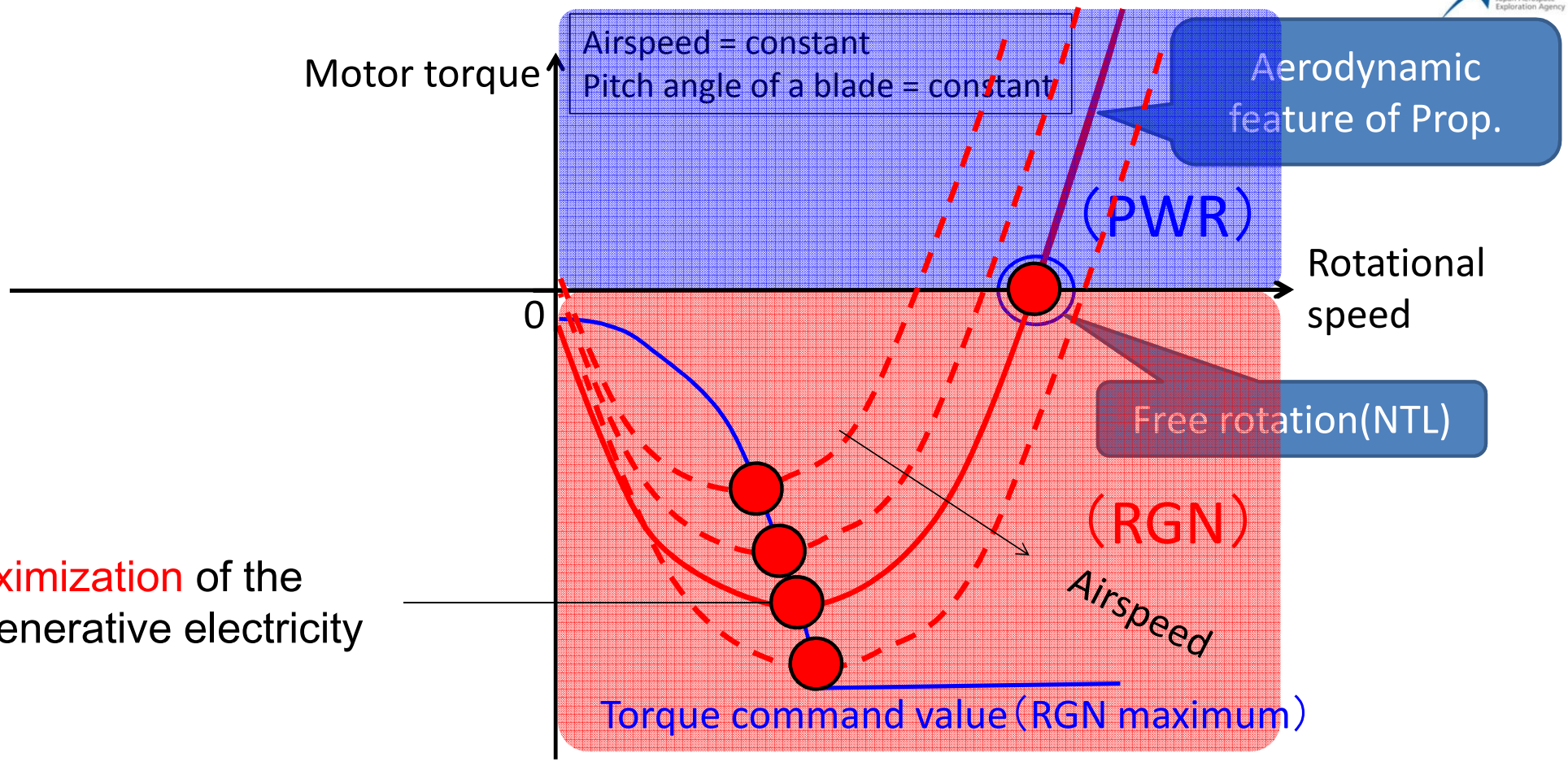
3.2 Regenerative air brake system(3/5)



3.2 Regenerative air brake system(3/5)

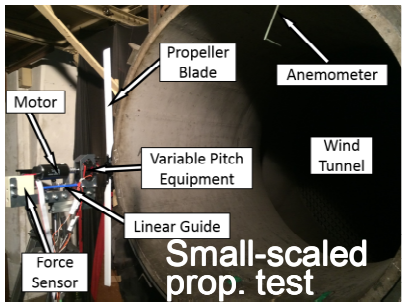


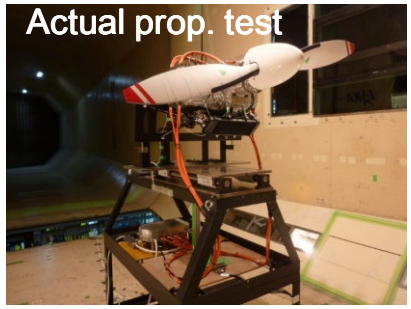
3.2 Regenerative air brake system(3/5)

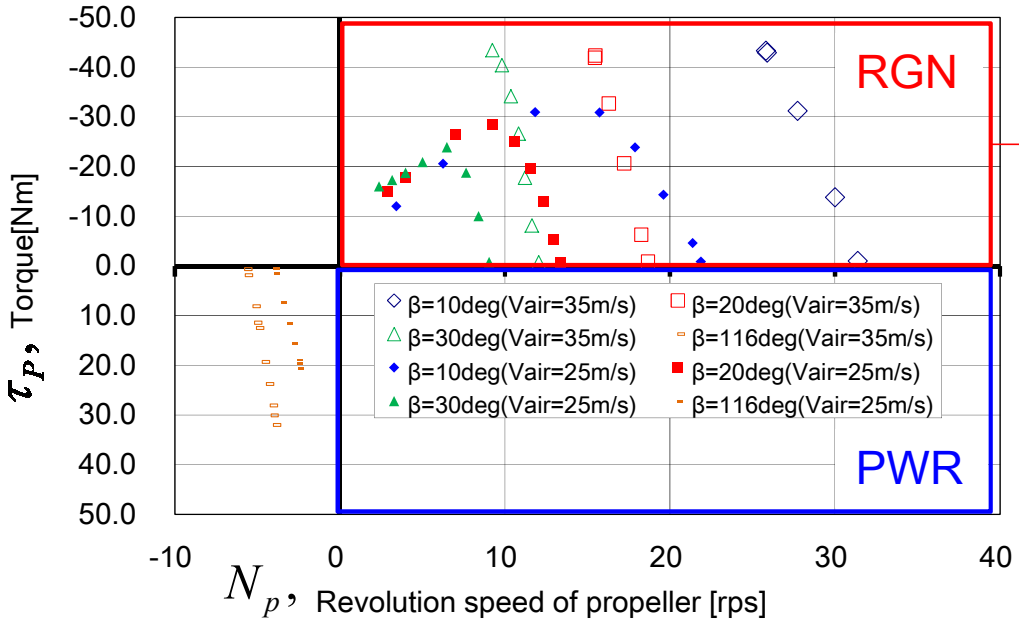


Maximization of the regenerative electricity

3.2 Regenerative air brake system(4/5)







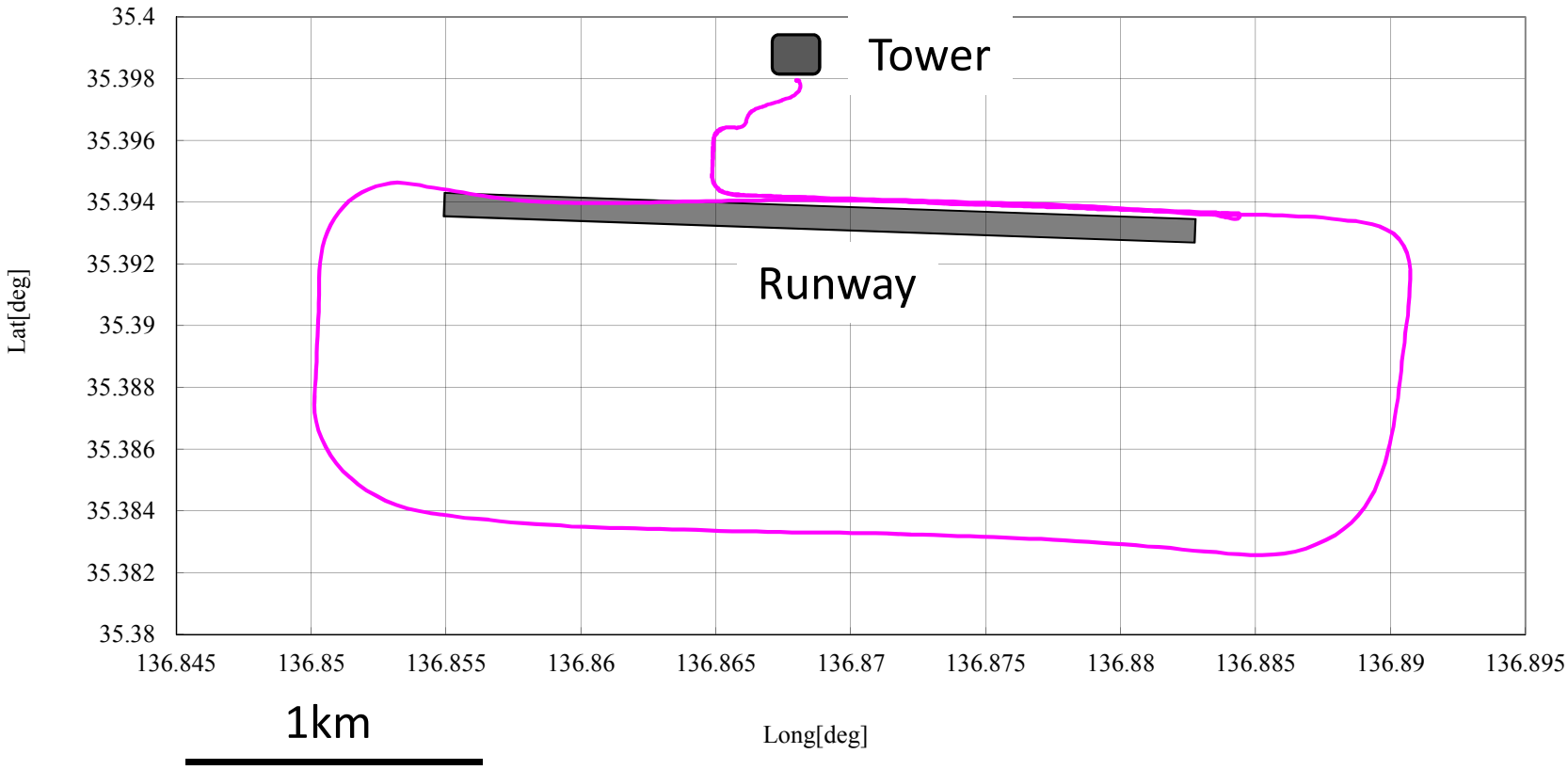
$$\tau_{P\max} = 2\pi C_{P\max} \rho N_p^2 D_p^5$$

The maximum torque is proportional to N_p^2 at a β value independent of V_{air}.

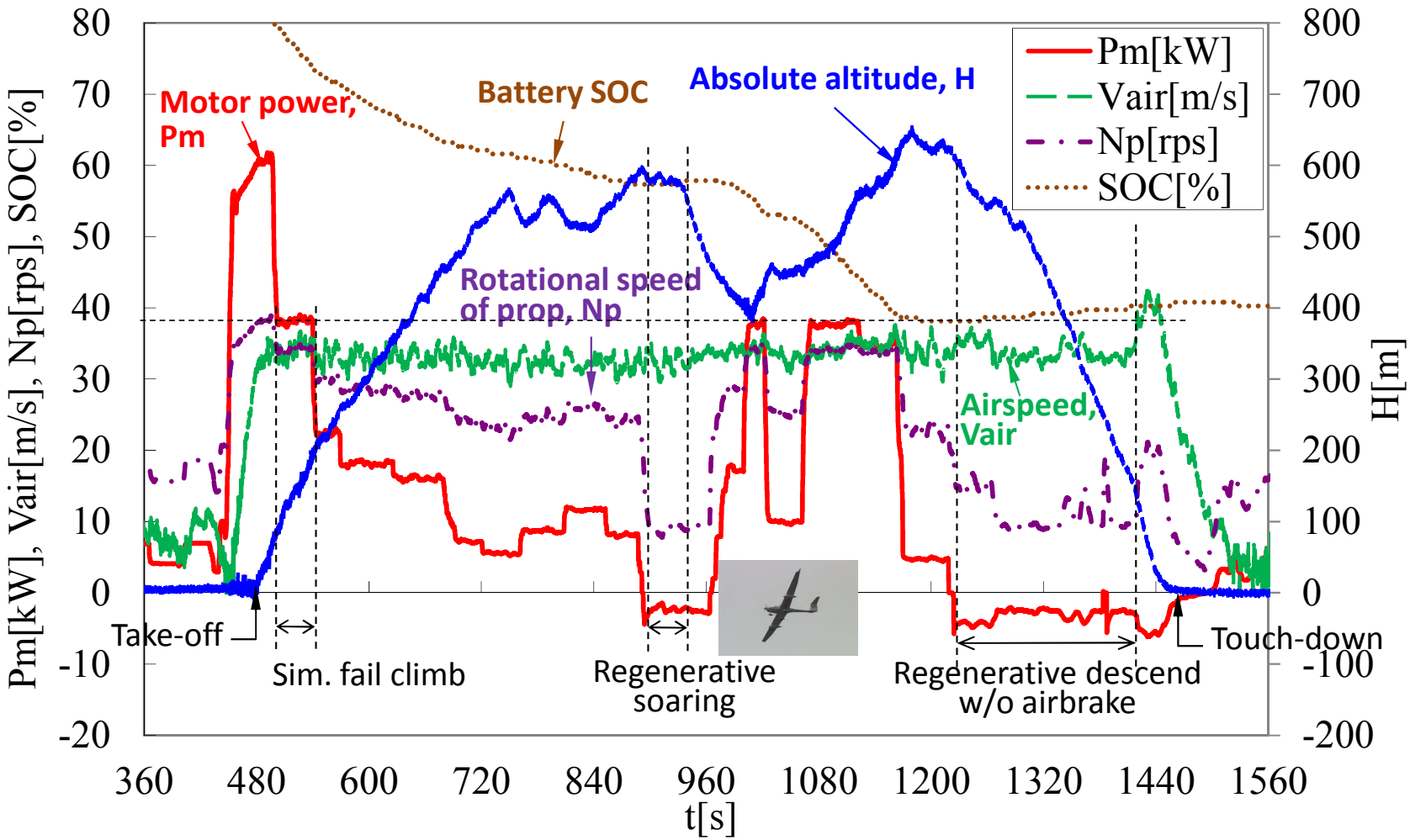
Wind tunnel tests results for the actual propeller in RGN mode

(The flight demonstration was mainly conducted at angle of propeller pitch, β=14deg)

4. Flight demonstration



Typical example of the short traffic path

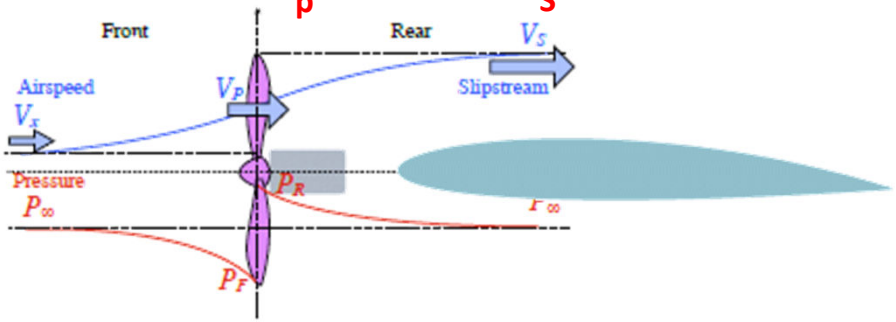
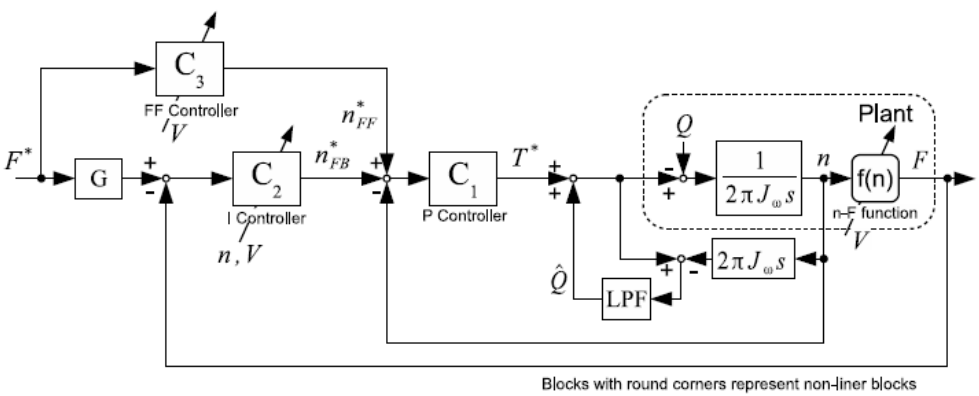


An example of flight test data

5. Summary

We have succeeded in flight demonstration as follows:

1. Avoidance of complete power loss in engine failure during climb by using the multiplexed electric motor
2. Regeneration of electricity about 8% of maximum motor output during descent
3. Control of descent rate by the proposed regenerative airbrake system without conventional airbrake
4. Continuous "regenerative soaring" free from descent in thermal condition

Acknowledgement: The wind tunnel test in this research was partly supported by the Ministry of Education, Culture, Sports, Science, and Technology grant (Basic Research A, number: 26249061)

$\Delta N_p \longrightarrow \Delta V_S \rightarrow \Delta L$