第28回　アストロダイナミクスシンポジウム

# 再使用ロケット実験機の現状と帰還飛行のダイナミクスに関する研究

# Present Status of Reusable Rocket Experiment and Study on Re-entry Flight Dynamics

Satoshi Nonaka
ISAS/JAXA

# Approach to Future Space Transportation

## High performance technology




Super light material
High performance engine
Reusable TPS …

**Innovation of Technology**

## Goal of future space transportation

| | |
|---|---|
| Flight frequency | ～10 flight/day |
| Total Payload（to LEO） | ～100 ton/day |
| Vehicle reusability | ～1000 flights |
| Engine reusability | ～100 flights |

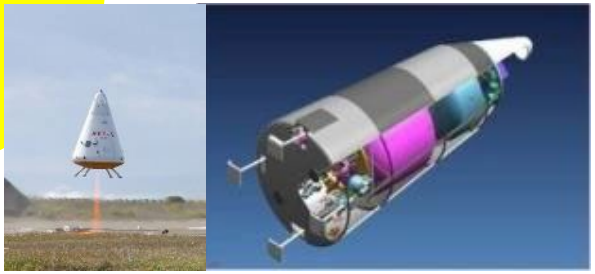

**Approach to Future Space Transportation**

**Innovation of Operations**

## Expendable vehicle


**Good Operability, Reliability, Safety**

## Reusable system architecture

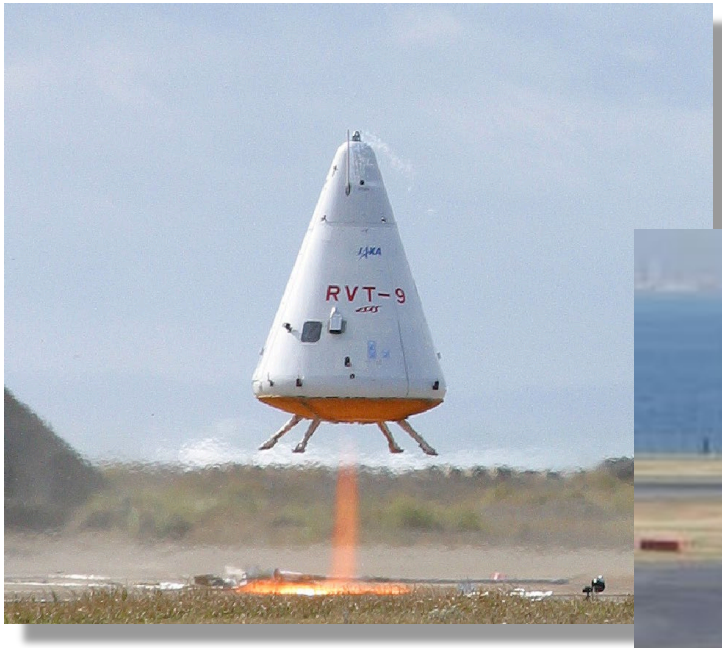


Reusable rocket vehicle

To realize frequent/mass space transportation in coming future, **good reusability** is important issue for reusable system architecture as well as high performance technology.

# Studies of Reusable Launch System

## Reusable System Architecture and Elementary Subsystem Studies




RVT
Reusable Vehicle Testing

- Repeated Flight & Turnaround Lessons
- Life-Controlled Engine Studies
- Landing Guidance Studies for Returning Flight
- Integrated Propulsion/Power System Studies

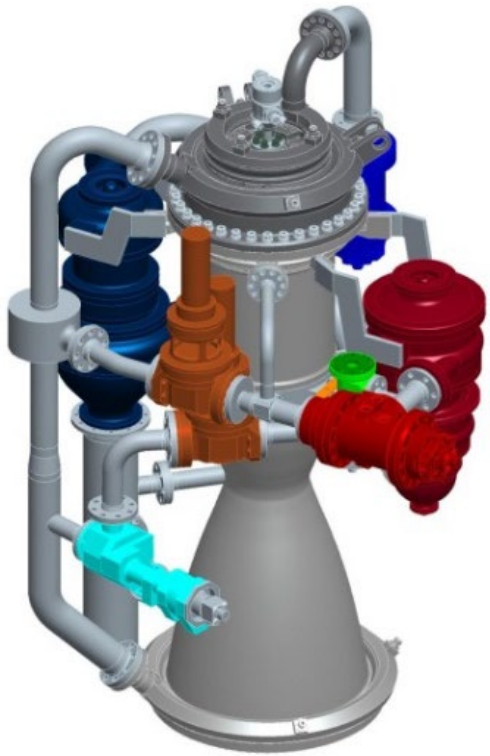
Reusable Sounding Rocket

- Ballistic flight >100km & return to launch site
- Liquid hydrogen propulsion / One day turnaround
- 100 times of reuse without major replacement
- Fault tolerant system of 1 failure-operative
- Weight minimizing & higher performance design lesson

# System Configurations of Reusable Sounding Rocket

| | |
|---|---|
| Body length | 13.5 m |
| Body width | 2.7 m |
| Take-off mass | 11.5 ton |
| Dry mass | 4.3 ton |

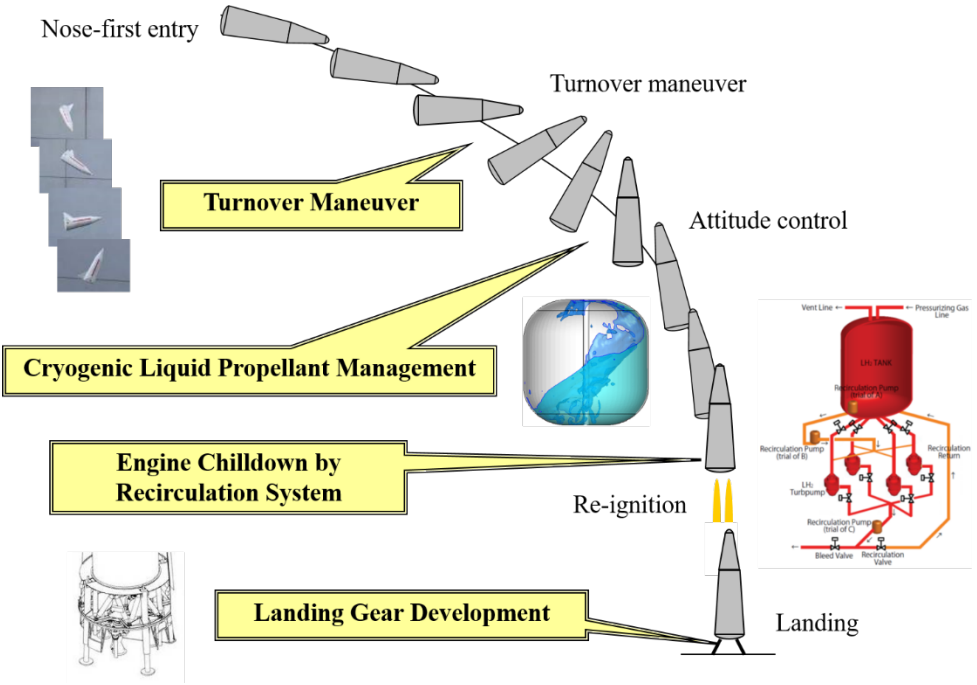
| | |
|---|---|
| Engine thrust | 41 kN × 4 |
| Engine Isp | 320 sec |
| Mixture ratio | 5.7 |
| Engine cycle | Expander Bleed |

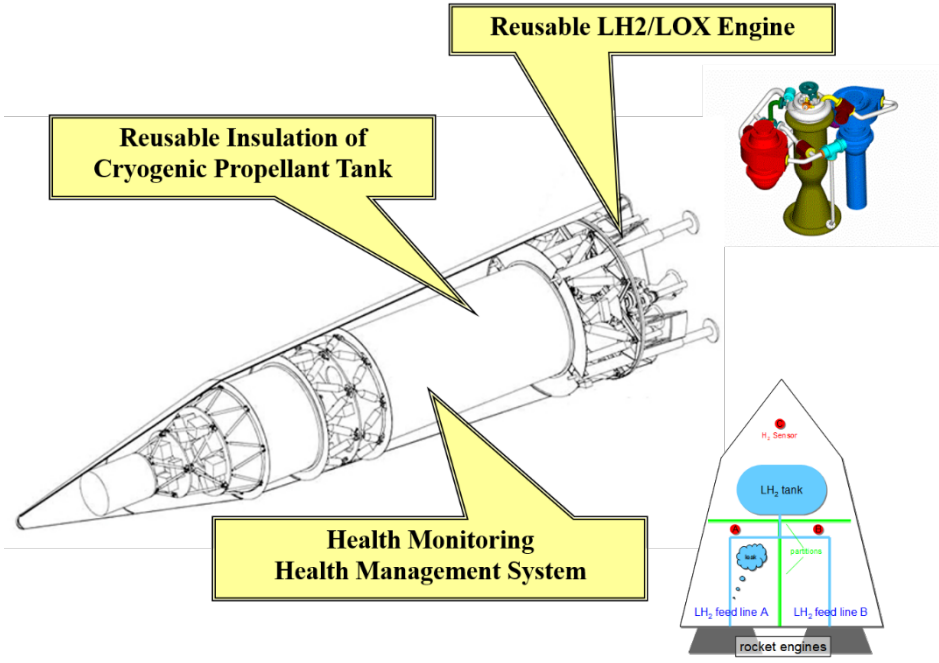
Main Engine

# Key Technology for Reusable Sounding Rocket Development

Before the development and manufacture of the operational reusable sounding rocket vehicle, we must verify the technical feasibility of the key technology for the reusable sounding rocket development.




Returning Flight Technology

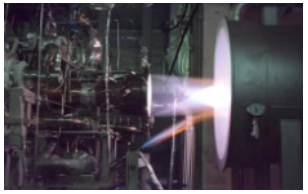



Repeated Operation Technology

# Technical demonstrations for reusable sounding rocket

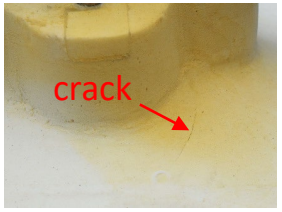
Demonstrations of the key and critical technologies to develop the reusable sounding rocket have been conducted for engineering verifications of subsystems.

## Reusable LH2/LOX engine



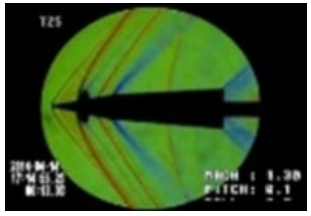
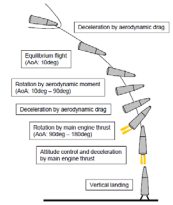

## Cryogenic liquid propellant sloshing

## Reusable insulation for cryogenic tank

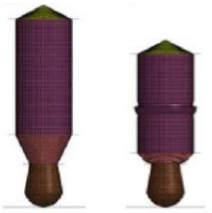




## Recirculation system for re-ignition

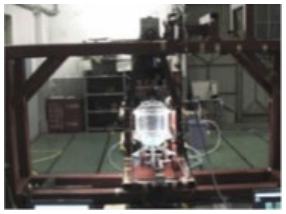

## Aerodynamics for returning flight

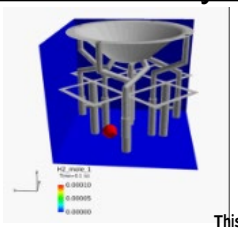

## Landing gear for vertical landing

## Cryogenic liquid propellant management

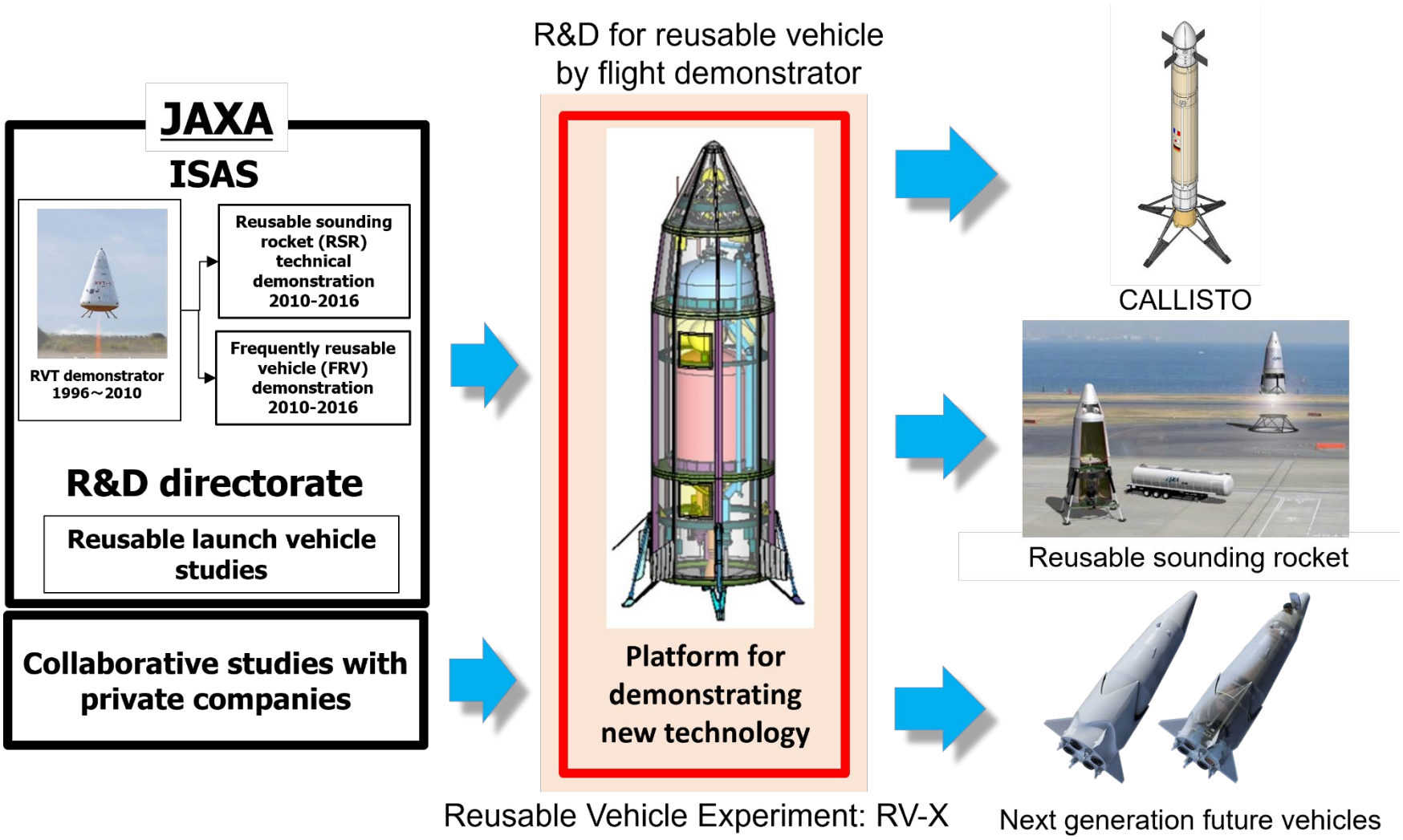



## Health management / fault tolerant system

# Flight demonstrator : RV-X

This activity is based on the technical outcomes obtained from studies in JAXA and collaborative studies with private companies.






Technical knowledge obtained from RV-X flight demonstrations will contribute to the system design of CALLISTO, reusable sounding rocket, and next generation future space transportation systems.

# Plan and Current status of the RV-X flight demonstration

RV-X system was developed by maximum use of existing components and technical outcomes obtained from related studies. As verification tests for flight demonstration, two series of stage firing tests have been conducted.

**FY2017**

System integration

Component integration

Engine gas tank propellant tank

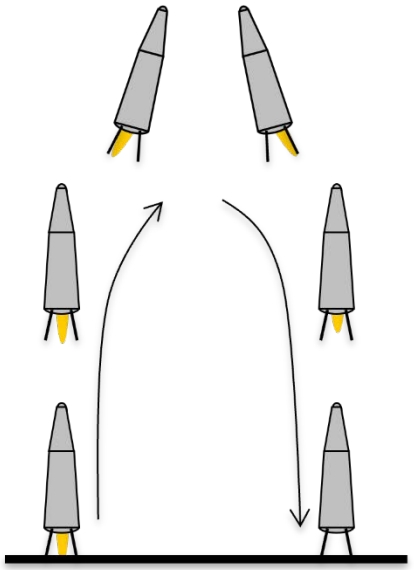
landing gear feed line Avionics

**FY2018 – FY2021**


【Stage firing test #1】
① Engine characteristics
② Propulsion characteristic
③ System operation
④ Vehicle environment data

【Stage firing test #2】
① Advanced engine characteristics
② Advanced propulsion characteristics
③ Vehicle environment
④ Ground operation
⑤ GNC characteristics
⑥ Quick turnaround operability

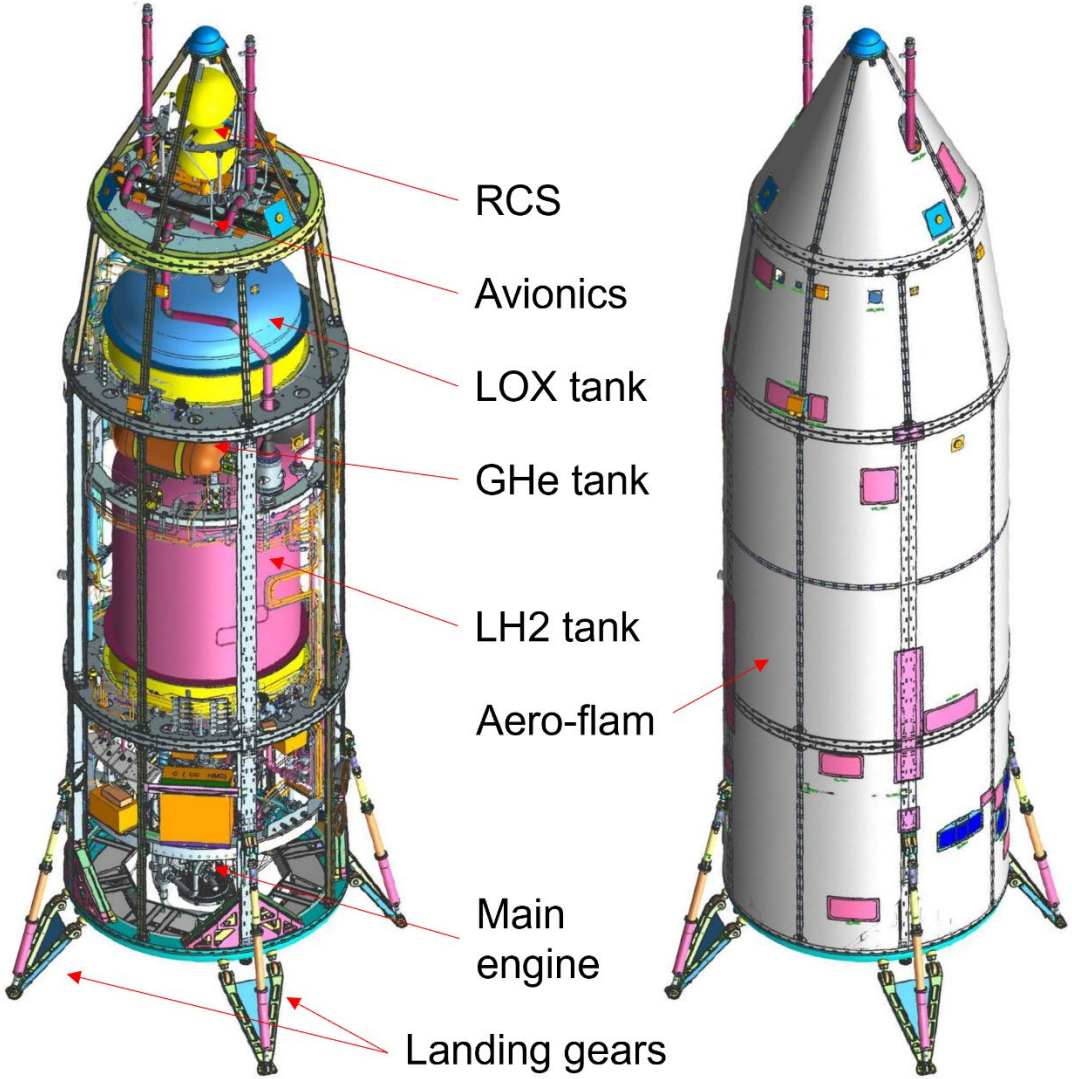
**Flight test**



**Demonstrate GNC & reusable operation**

- Lift off and landing operation by powered flight
- Deep throttling by pump fed engine
- Gimbal control
- Turn around operability
- ・・・・・・・・・

# RV-X: Reusable Vehicle Experiment




Configuration of RV-X

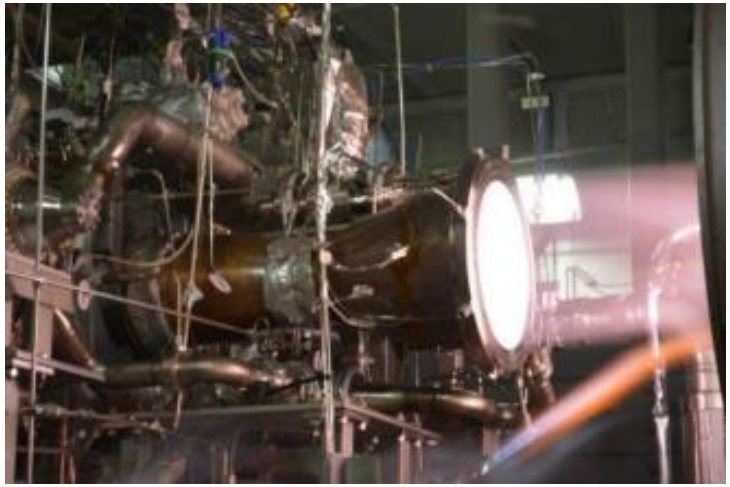
| | |
|---|---|
| Total length | 7.3 m |
| Diameter | 1.8 m |
| Dry mass | 2.0 ton |
| Take-off mass | 3.0 ton |

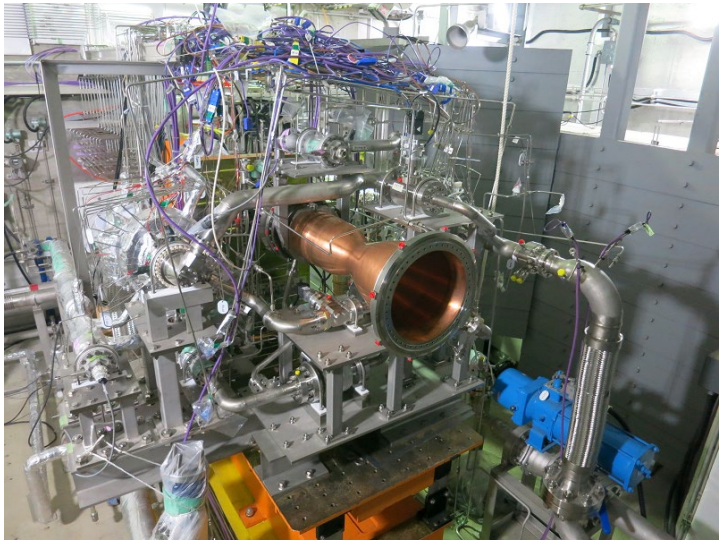
<u>Attitude control</u>

Roll: RCS by GN2 cold gas jet

Pitch/Yaw: engine gimbaling by electric actuators.

# Engine System





Flight engine of RV-X is assembled by existing LOX/LH2 reusable engine developed in technical demonstration for reusable sounding rocket.

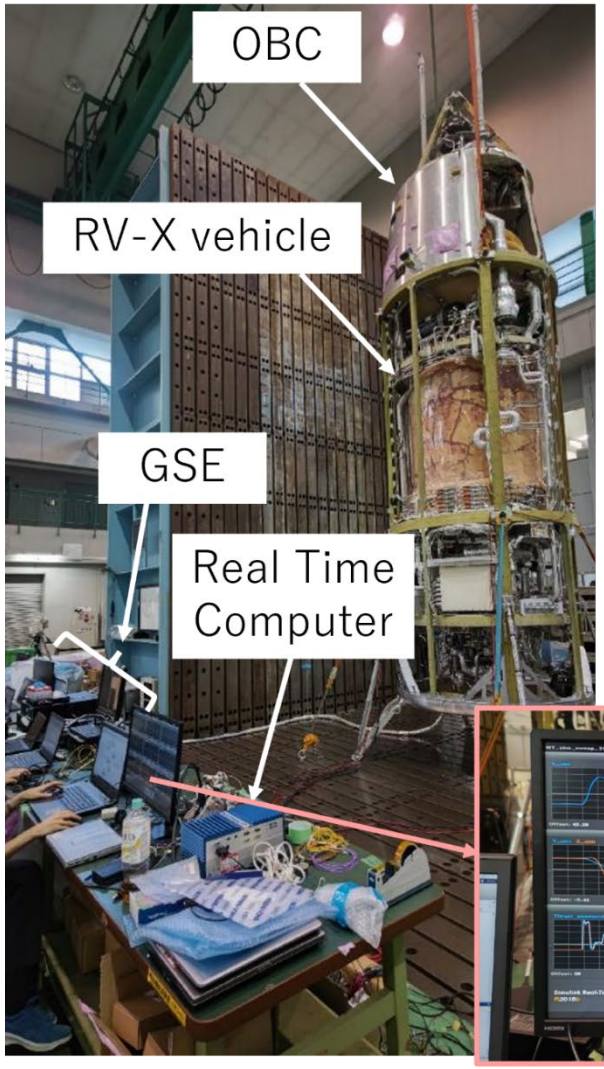
Engine system characteristics

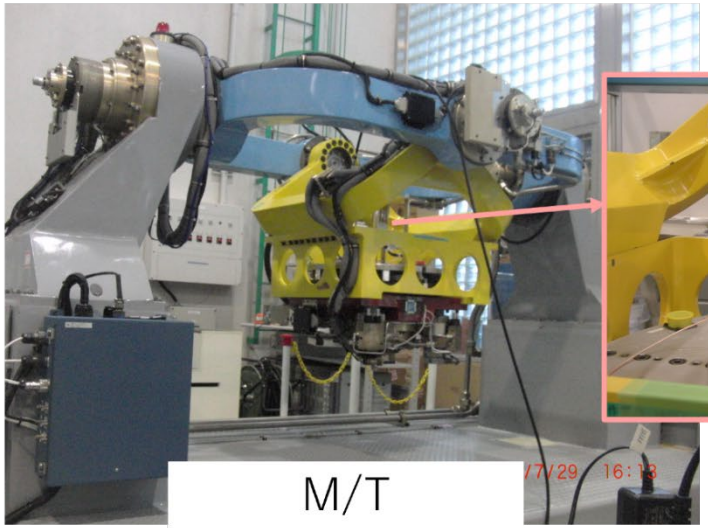
| | | |
|---|---|---|
| Engine cycle | Expander bleed | |
| Throttling range | 100% ～ 40% | |
| Engine thrust | 41 kN | 16 kN |
| Engine Isp | 320 sec | 270 sec |
| Combustion chamber pressure | 3.4 MPa | 1.6 MPa |

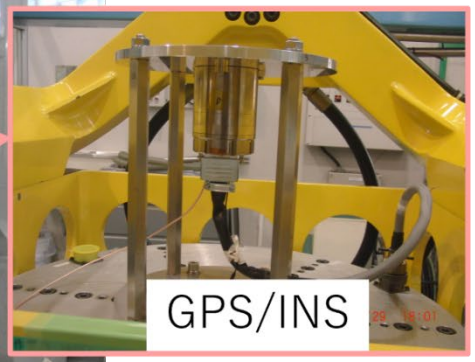

Flight engine of RV-X

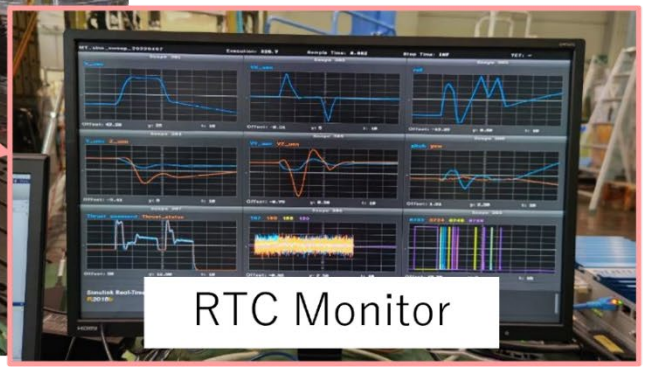
# Motion Table (M/T) Test for GNC System

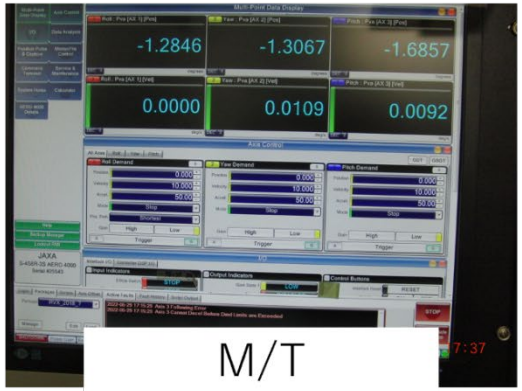
M/T test has been conducted for verification of GNC system. M/T is a highly verified flight simulation by a motion table facility and a GPS simulator incorporating actual GPS/INS. Functions of GNC system combining OBC and other flight hardware were confirmed in the case of the nominal flight and the emergency landing transition



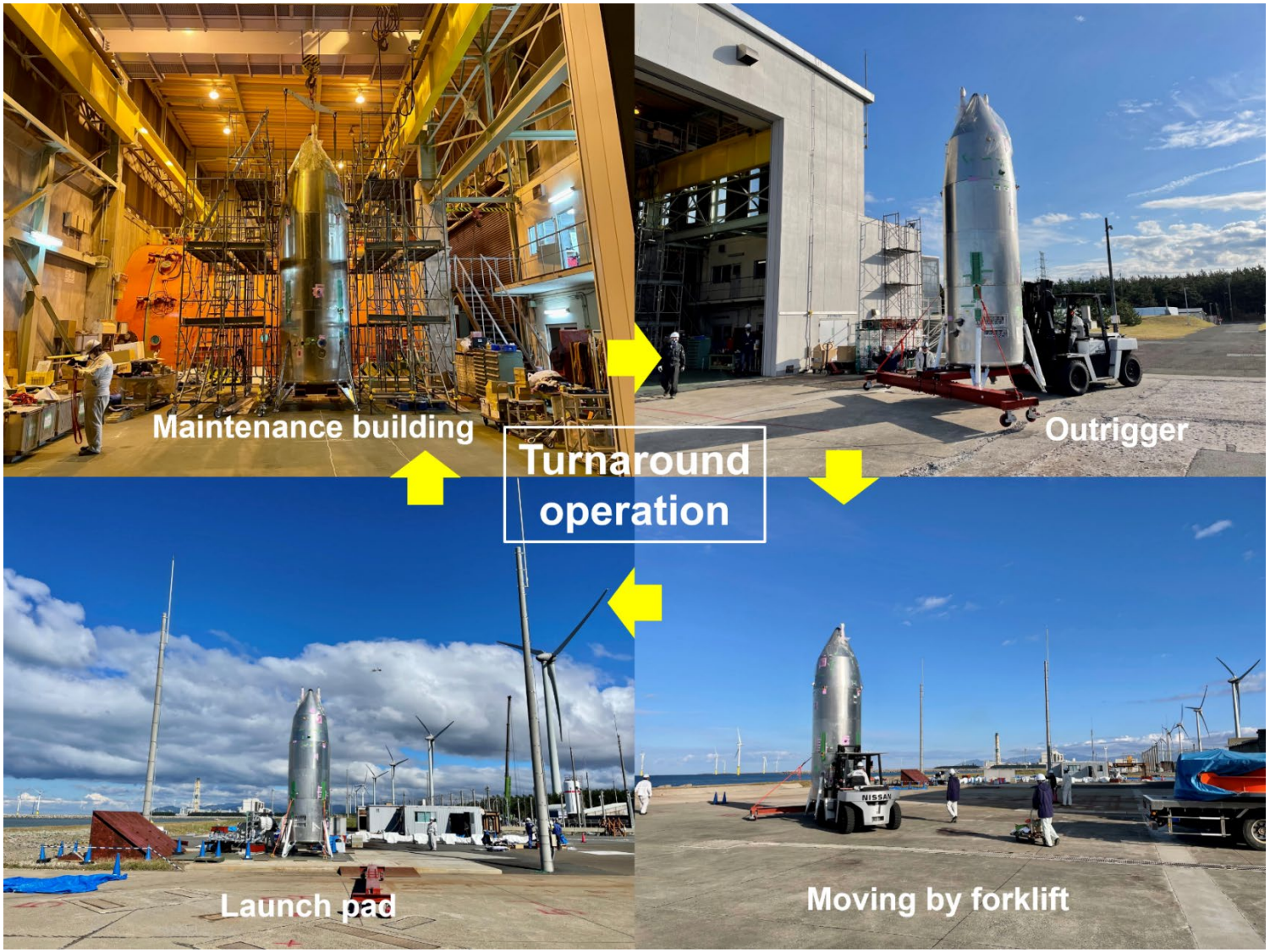




ISAS/JAXA Sagamihara

# Ground Operation Test

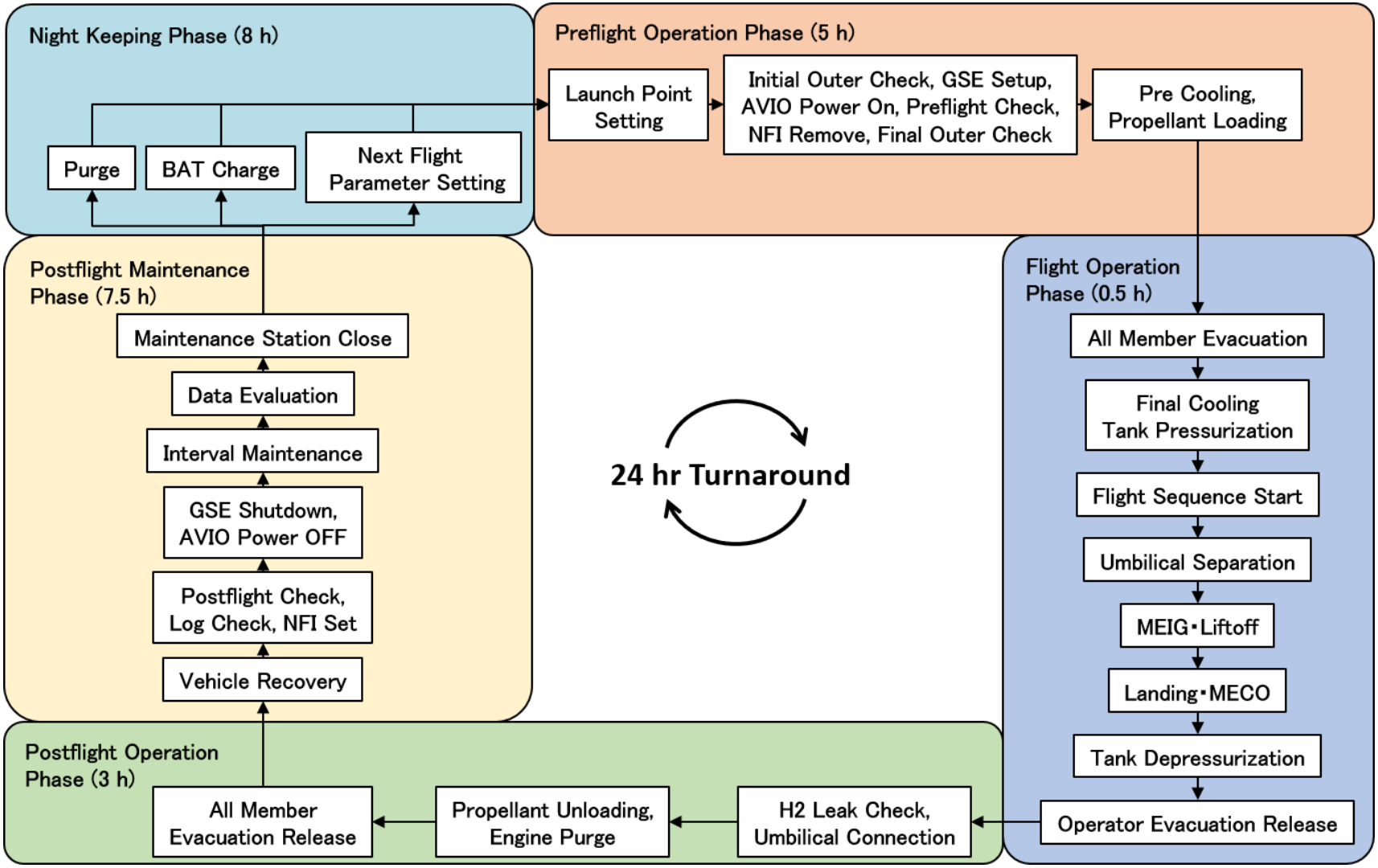
To confirm the characteristics of repeated operation and the interface between the RX-V vehicle and the ground support systems, a ground operation test was conducted in preparation for flight tests using the RV-X vehicle.




Noshiro Rocket Testing Center

# Turnaround Operation

The goal of operation sequence of the flight test is to realize a quick turnaround within 24 hours. In the RV-X system integration, aiming the turnaround to be shorter than the other present reusable vehicle, each component is designed and assembly with high durability, minimizing replacements, and easy to access at the maintenance.



# Studies on Reusable Rocket Systems

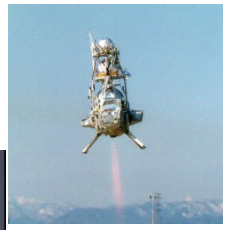
1998 — 2010 — 2016 — 現在

## 再使用ロケット実験機 RV-T

繰り返し飛行運用の実証と設計経験の蓄積

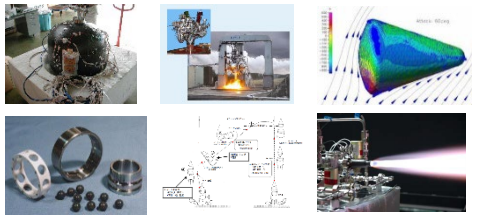
第1次実験（1999）
液水ロケットの
繰り返し飛行

第2次実験（2001）
飛行範囲の拡大／飛行誘導
の洗練，耐久性エンジン設計



第3次実験（2003）
複合材極低温タンク
電鋳製インジェクタ
飛行範囲の拡大

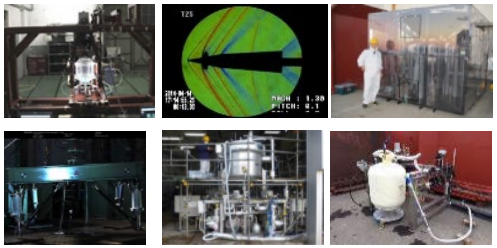
再使用ロケットの要素技術実証



軽量タンク，離着陸時の空力特性評価
ヘルスマネージメント，RCS試作など

## 再使用観測ロケット 技術実証プロジェクト

機体システムに係わる技術実証



ロケットタンクや着陸脚試験等の機体を
構成する部位の基礎的な試験

エンジンシステムに係わる技術実証

40%推力　70%推力

100%推力

エンジンスロットリング制御実証の様子

## 再使用ロケット実験機 RV-X


飛行実証プラットフォームの構築
＋
要素技術の実証
II
再使用関連技術の獲得

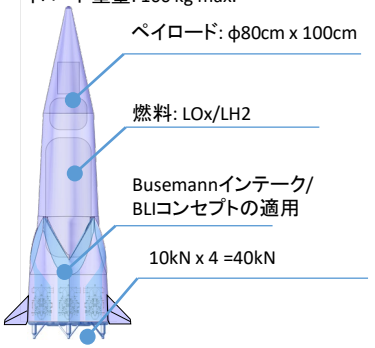
現在地上燃焼試験#2実施中
飛行試験に向けた準備中

## 小規模飛行計画 ~2024

- ATRエンジンの技術実証
- 低高度離着陸試験

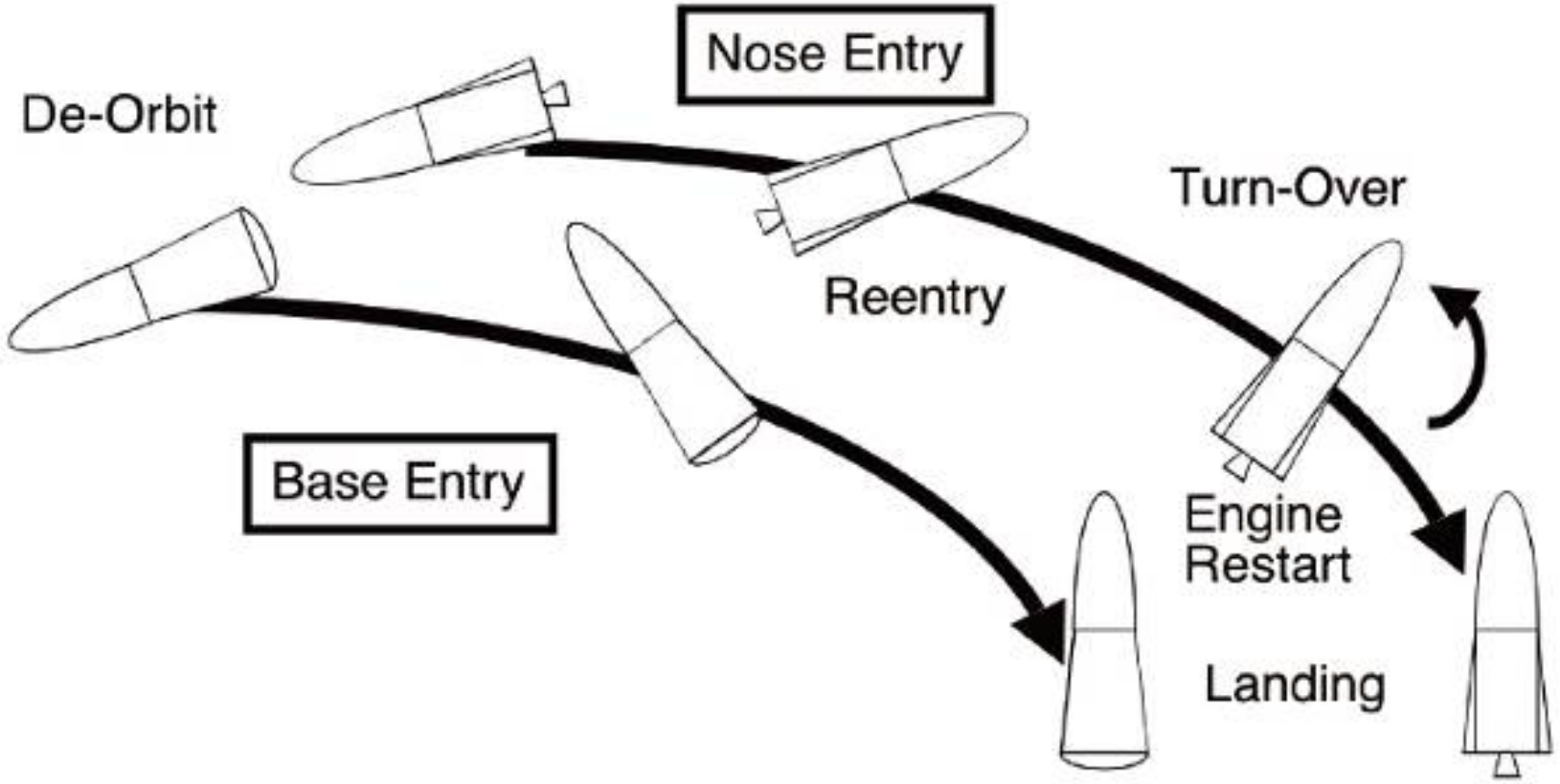

## 再使用観測ロケット ~2027

目標高度: 130 km max.
目標飛行時間: 180 sec max.
ペイロード重量: 100 kg max.

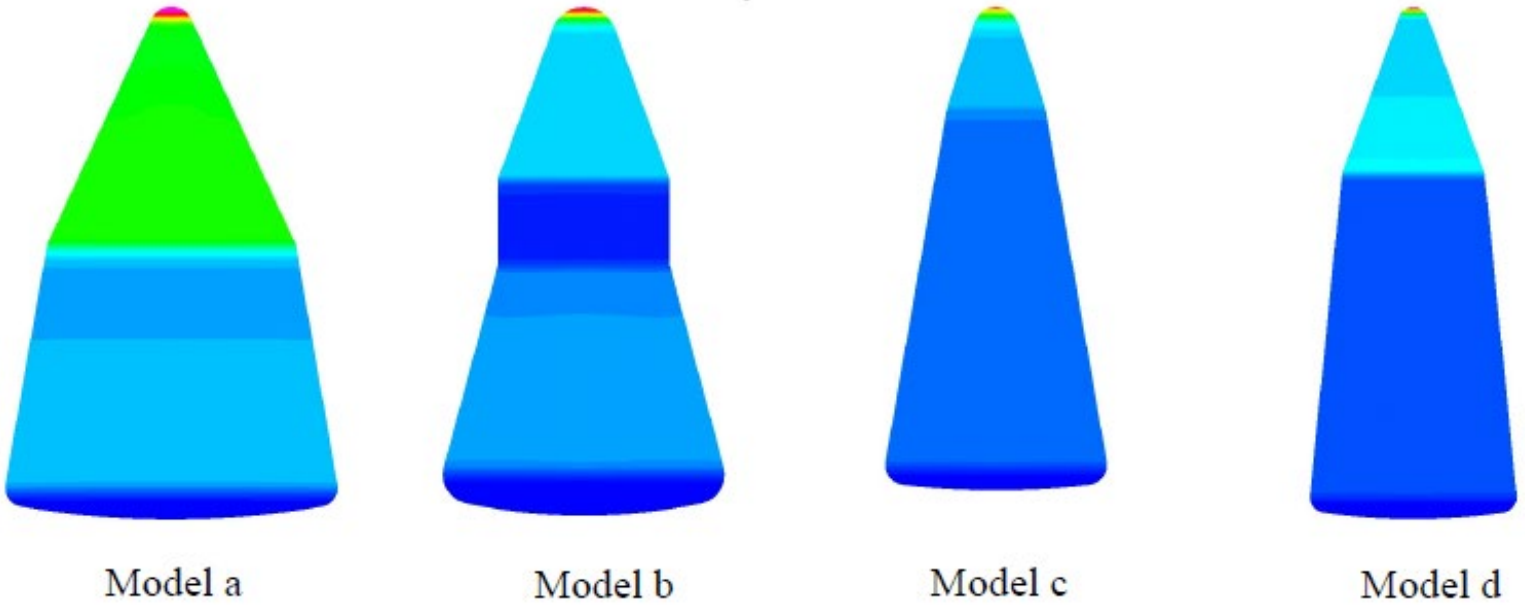


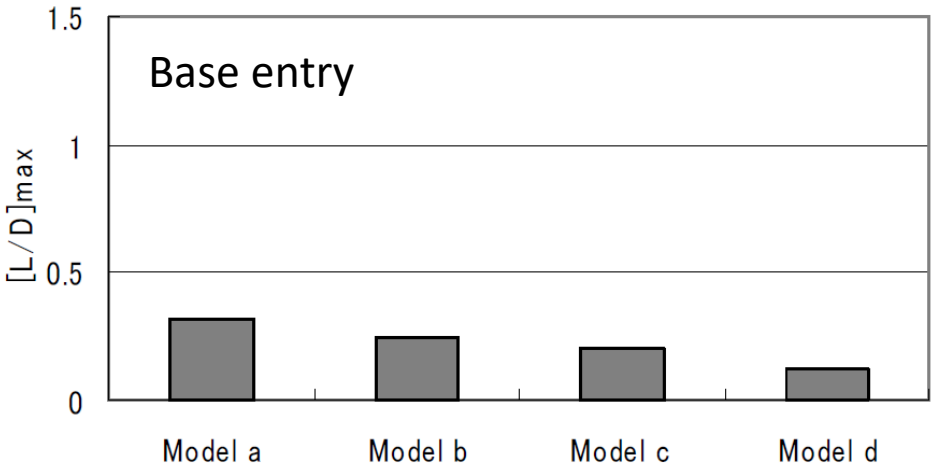

# 小規模実験機による段階的な技術獲得～将来への発展

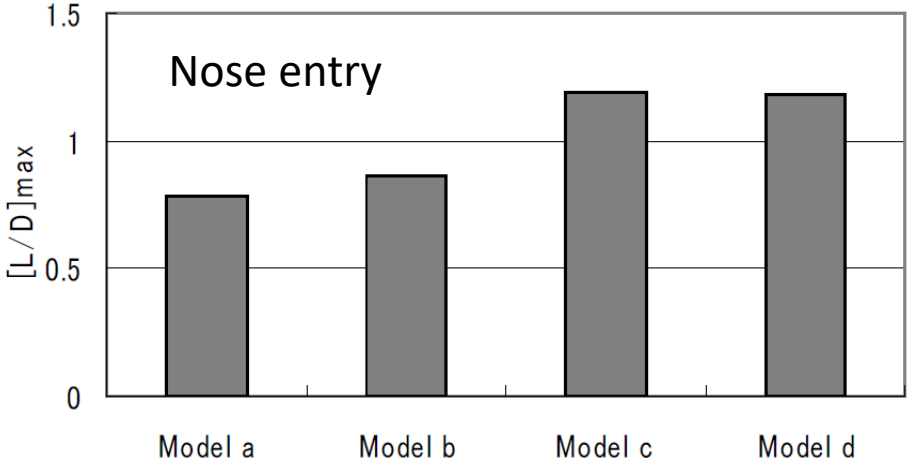
# Re-entry Flight of Reusable Rocket Vehicle



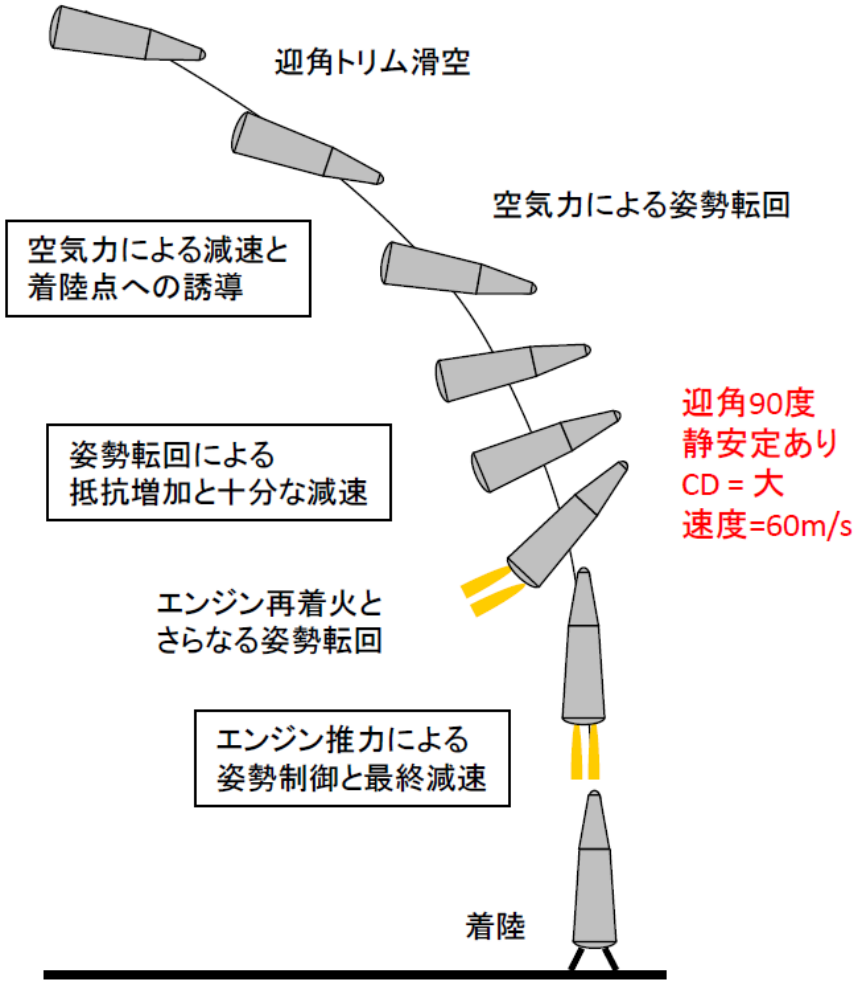
# Vehicle Configurations and L/D



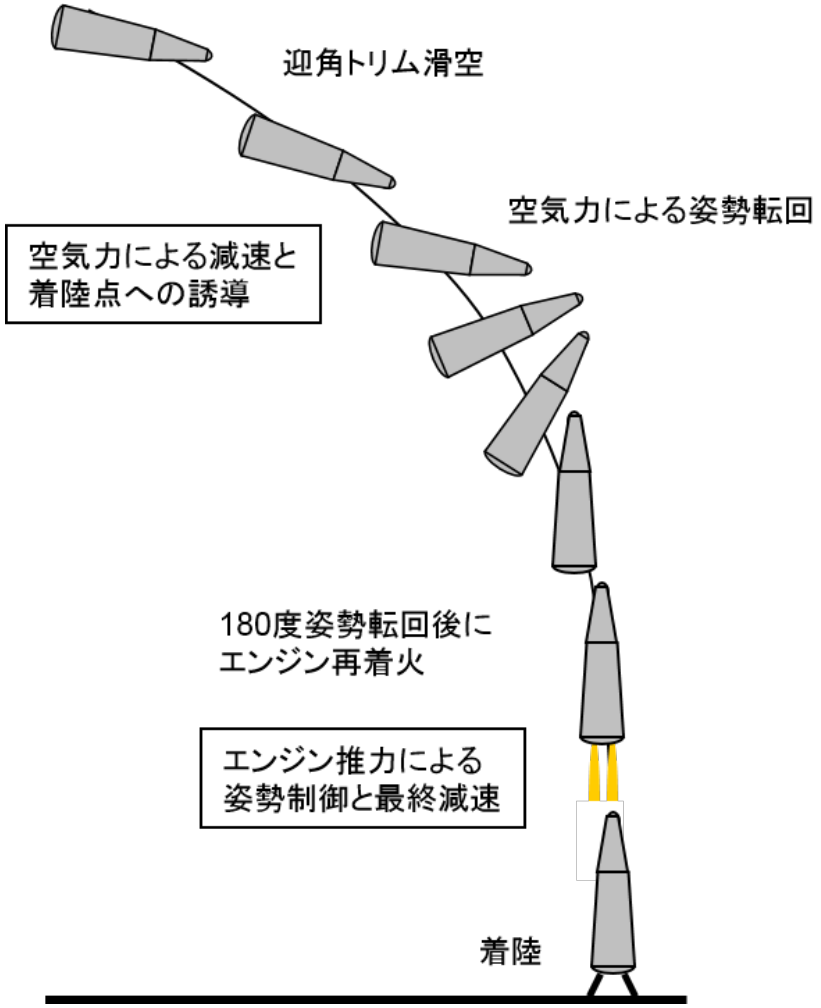



# Minimizing Propellant for Returning Flight and Landing

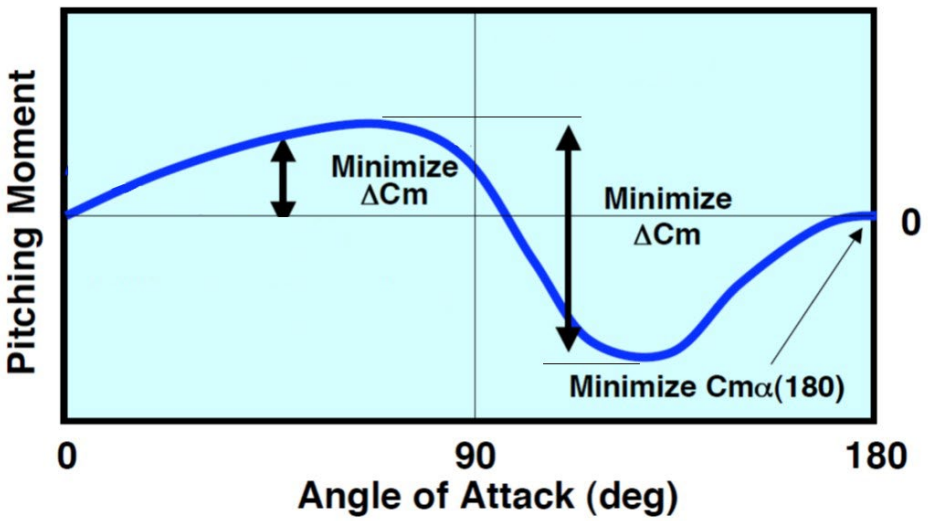



エンジン推力による転回

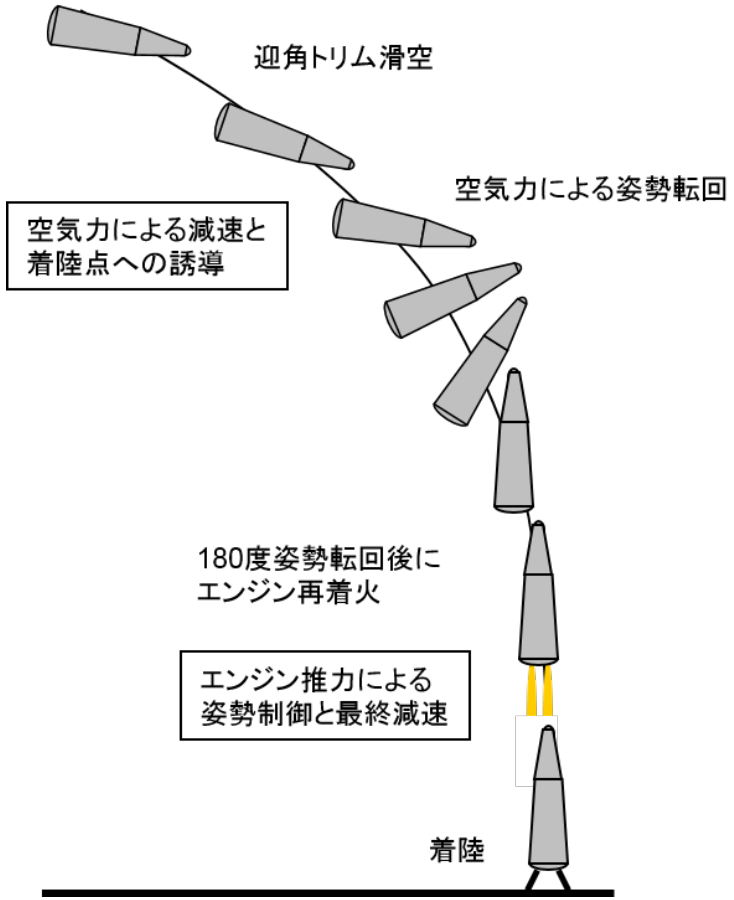



空気抵抗を最大限利用した転回・減速

# Aerodynamics during Turnover Maneuver




細長物体の迎角0-180度におけるCm

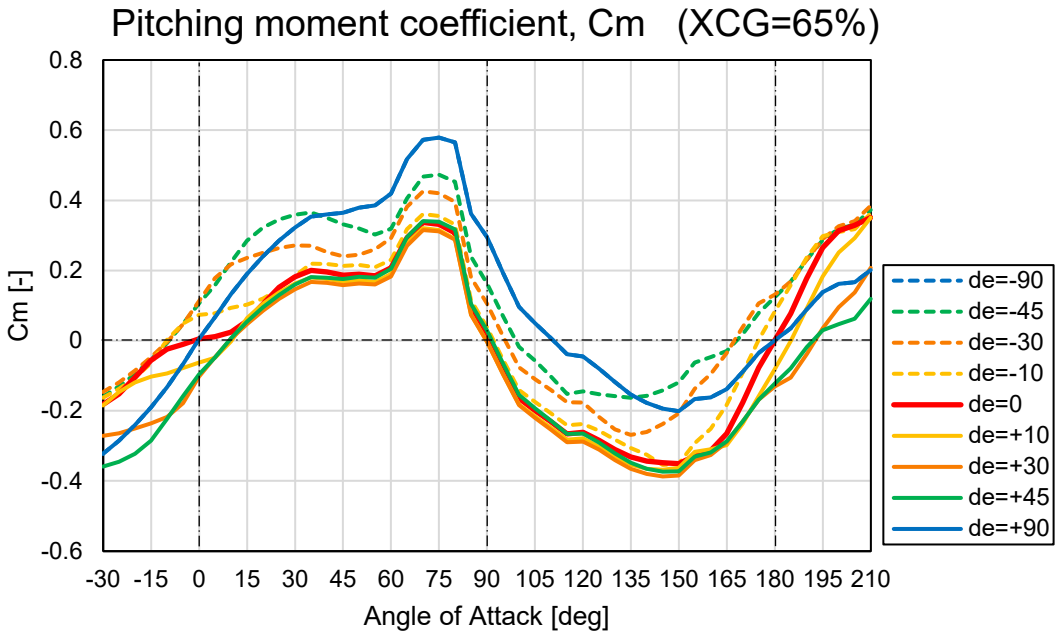


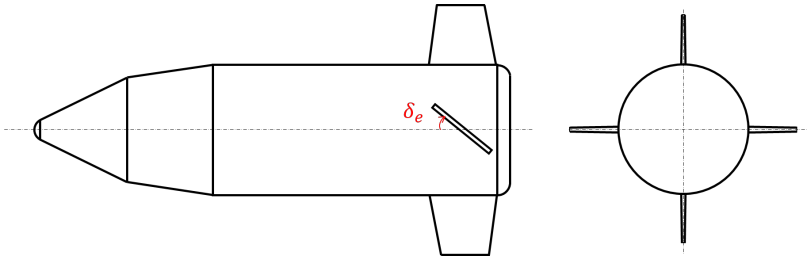

着陸前の姿勢転回運動



Nonaka et al. ISTS 2008

# Aerodynamics during Turnover Maneuver

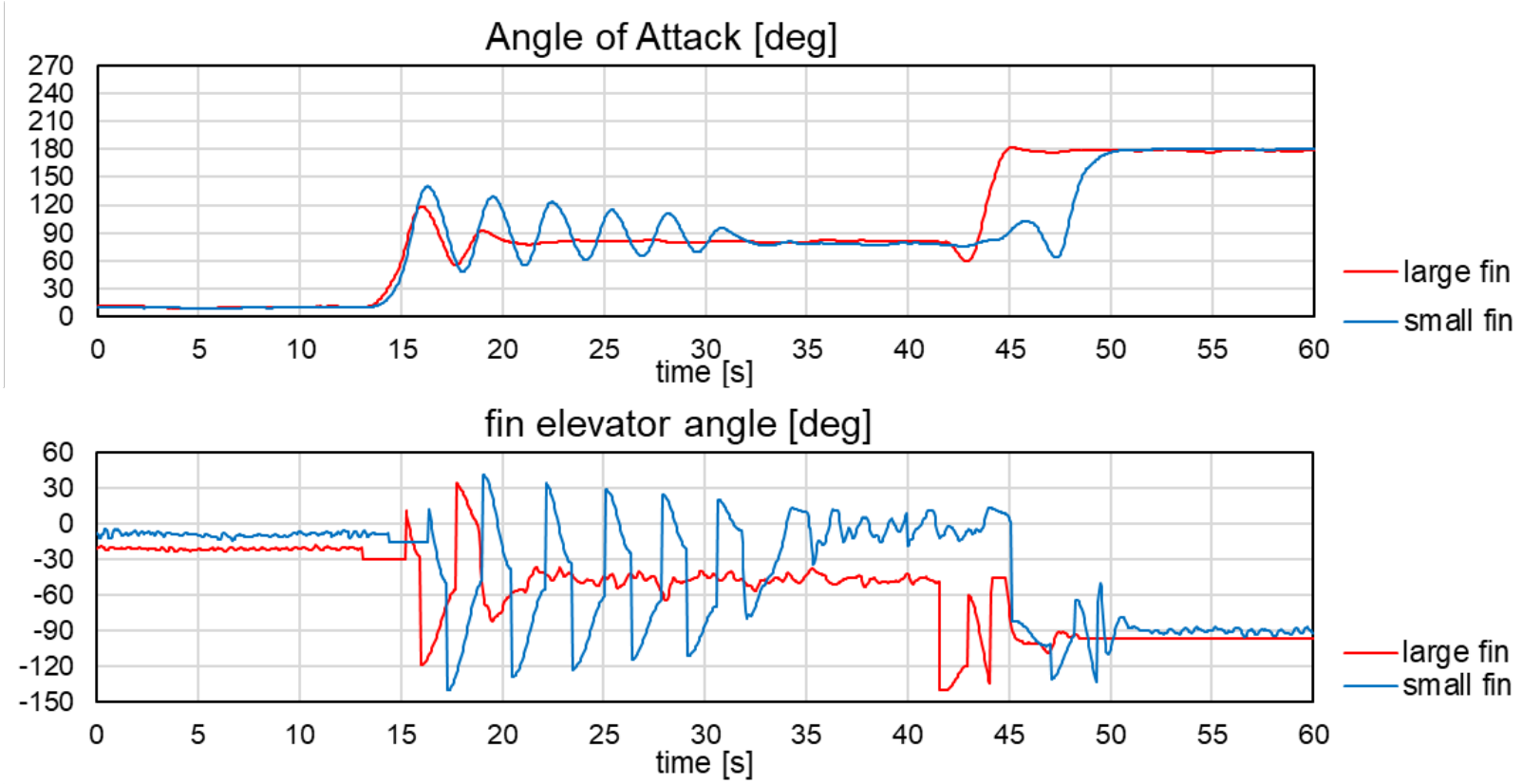



胴体：RV-X形状
尾翼：左右対称テーパ翼x4
　　胴体底面積x0.22

- 姿勢運動の成立性評価はピッチングモーメントCmの迎角特性および尾翼の舵効き特性が重要
- 基本特性：　$\alpha$ =0 まわりで静的不安定　　$\alpha$ =0~90deg　　：Cm>0
  　　$\alpha$ =90 まわりで静的安定　　$\alpha$ =90~180deg　：Cm<0
- ピッチングモーメント特性は機体重心位置にも依存

# Attitude Control by Fins

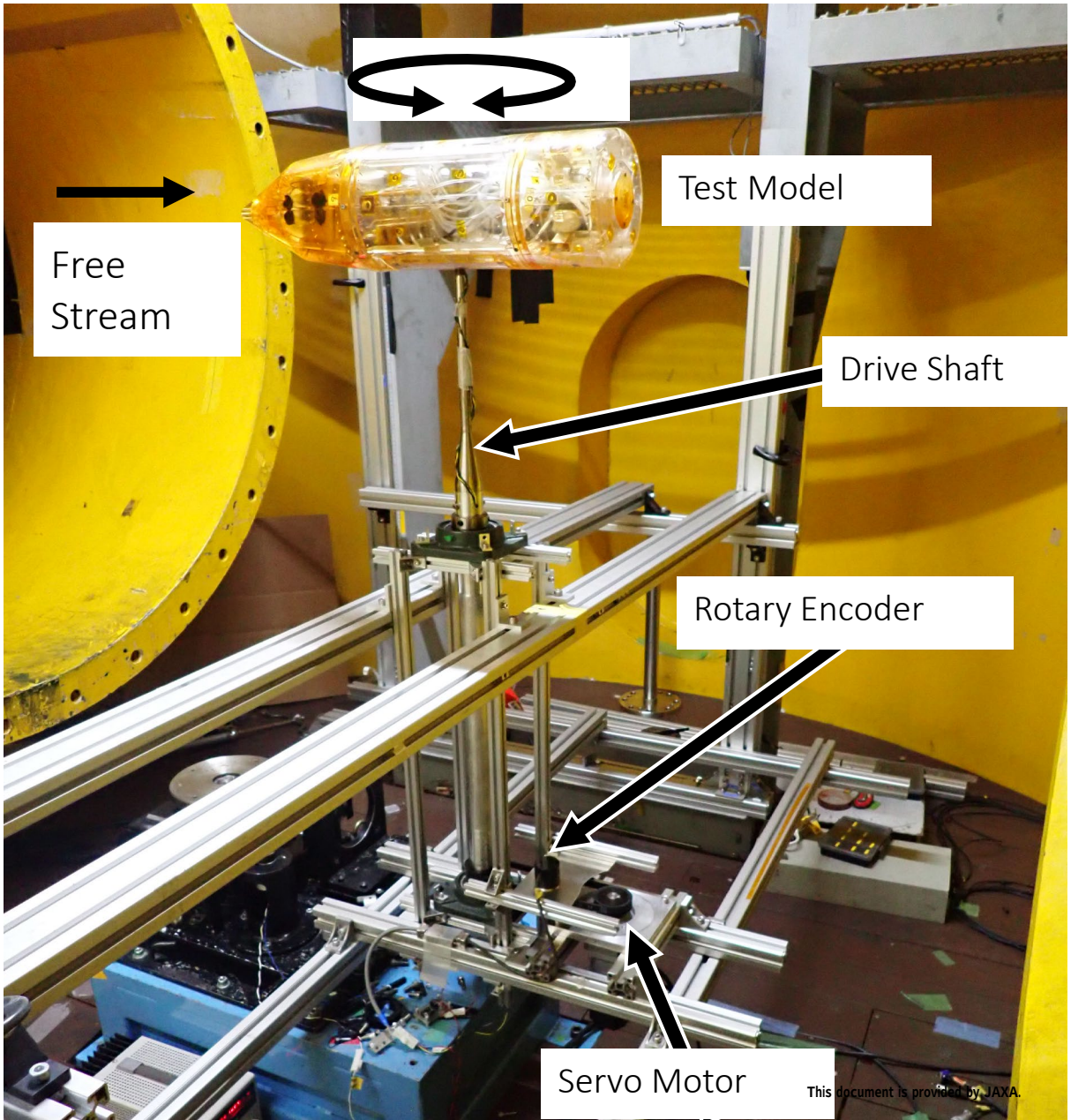



- 尾翼が小さいと舵効きが小さいため、転回時に何度か姿勢を往復させる必要がある
- 尾翼が大きいと舵効きが大きいため、転回後すぐに目標迎角に移行することができる

※玉井亮多、他 2023

# Wind Tunnel Tests for Surface Pressure Measurement

- Wind tunnel experiment
  - LWT at ISAS / JAXA.
  - 1.6 m dimeter circular test section.
  - Model was rotated by a drive shaft and a servo motor as pitching motion.

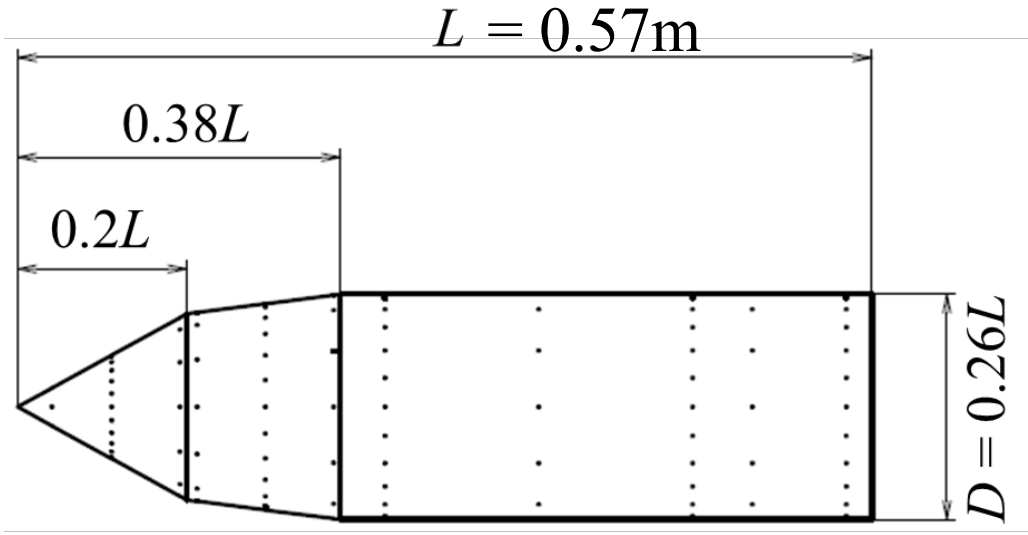



Experimental Setup

# Experimental Model and Pressure Measurement

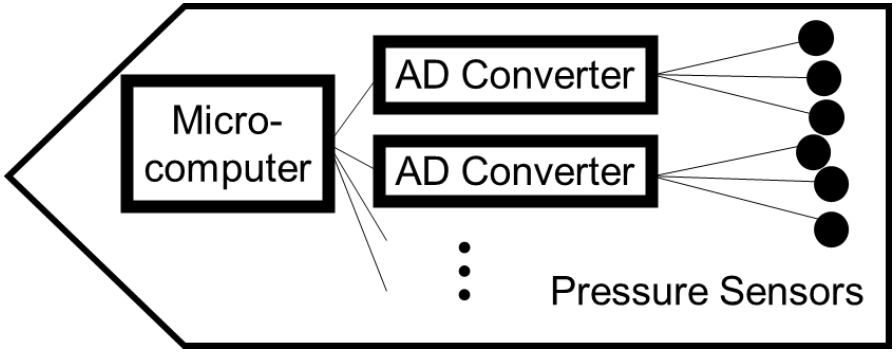
- Wind tunnel test model
  - 1/12 scale of RV-X

  (Reusable Vehicle eXperiment)
  - 184 pressure taps on surface
  - Pressure measurement system intern
- Pressure measurement system
  - 40 samplings instantaneously
  - 800 Hz sampling rate
  - ±5 Pa error




Model dimension and pressure taps location

Inside of model




Pressure measurement system schematic