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SPACE ELEVATOR ROAD MAP 2010

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ABSTRACT

In 2010, members of the Japan Space Elevator Association (JSEA) started developing a draft version of the Space Elevator Road Map. We reviewed and discussed (1) Key Milestones in Japanese National Policy, (2) Scope of Study needed by JSEA members. After that, we started a monthly study meeting to discuss on (a) Feasibility Study and (b) System Requirements so that we can make 'Road Map'. In this manuscript, the study teams activities are summarized such as: (A) Draft version of Mission Definition as part of Feasibility Study, (B) Draft version of Conceptual Design of Space Elevator as part of Feasibility Study, (C) Draft Cost Feasibility Study as a part of Feasibility Study, (D) Gathering Study/Research of Core Technology to accomplish Space Elevator as a part of System Requirements development.

1. DEVELOPMENT APPROACH OF SPACE ELEVATOR ROAD MAP

It is difficult to say when we can have a Space Elevator because of mainly two reasons below:

- ✓ When can we have strong enough material in reasonable price to make Space Elevator Tether?
- ✓ Is there any user to use Space Elevator to reduce cost transferring things to Space?

If we wait for these too much, we have never started to design Space Elevator. But it is good to have some specific goal to think about Road Map. Therefore, members of Japan Space Elevator Association discussed how we develop Space Elevator Road Map at the beginning.

- Step 1 Find Key Technology Milestones, Japanese National Policy
  - ➢ Strategic Technology Road Map by Minister of Economy, Trade and Industry
  - ➢ Basic Plan for Space Policy by Strategic Headquarters for Space Policy, Prime Minister of Japan and His Cabinet
- Step 2 Define scope of our Road Map

development
- Step 3 Monthly meeting
- Step 4 Present Annual Report at Space Elevator Conference in Japan
- Step 5 Summarize at International Astronautical Congress every year

2. KEY MILESTONES FROM JAPANESE NATIONAL POLICY

We found two Japanese National Policies to answer our questions as:

- ✓ When can we have strong enough material in reasonable price to make Space Elevator Tether?
- ✓ Is there any user to use Space Elevator to reduce cost transferring things to Space?

2.1. Strategic Technology Road Map by Minister of Economy, Trade and Industry of Japan

There is "Space Elevator" in 2050 on the Strategic Technology Road Map by Minister of Economy, Trade and Industry of Japan.

2.2. Basic Plan for Space Policy by Strategic Headquarters for Space Policy, Prime Minister of Japan and His Cabinet

There are six basic pillars for "Better Quality of Life" and "Contribution to the international community":

- Ensure a Rich, Secure and Safe Life
- Contribute to Enhancement of Security
- Promote the Utilization of Space for Diplomacy
- Create an energetic future by promoting R&D of the forefront areas
- Foster Strategic Industries for the 21st Century
- Consider the Environment

Space Solar Power System is selected as one of four Research & Development Programs of Japanese Space Program.

3. SCOPE OF SPACE ELEVATOR STUDY BY JSEA MEMBERS

Using 'Standard Approach of Space Development' as follows:

- Phase A: Feasibility Study (Conceptual Design)
- Phase B: Requirements Definition
- Phase C/D: Design / Manufacturing / Verification
- Phase E: Operational usage.

This study focuses on Phase A and B above. This means the main products of this study will be listed below:

- Feasibility Study Phase
  - ➢ Mission Definition
  - ➢ Conceptual Design of Space Elevator
  - ➢ Feasibility Study of Conceptual Design
- Requirements Definition Phase
  - ➢ Space Elevator System Requirement

As a result of the study, SE Road Map will be updated every year.

4. FEASIBILITY STUDY

4.1. Mission Definition

First, we talked about the final goal of this "Space Elevator Program" and wrote down what kind of service (i.e. demand) should be provided from the Space Elevator.

- Products Transport
  - ➢ For Space: Assembly of Space Structure, Food, Water, Fuel
  - ➢ For Earth: Natural Resources from Moon, Agricultural Products
- Human Transport
- Satellite/Explorer Deployment/Retrieval
- As a part of Geosynchronous Earth Orbit (GEO) Station Function
  - ➢ Space Transport Station (like a train station)
  - ➢ Space Solar Power System
  - ➢ Space Depot (or Intermediate Maintenance Facility): On-Orbit Repair Shop
  - ➢ Space Farm
  - ➢ Space Experiment facility
  - ➢ Space Hotel, Restaurant, Exercise Facility, Hot Spring

4.2. Conceptual Design of Space Elevator

In this year, we drafted its conceptual design.

4.2.1 Draft version of Conceptual Design of Space Elevator

To accomplish the demand described on the previous slide, we drew conceptual design of the Space Elevator as a starting point to talk about Road Map. (Figure 1)

- On-orbit Space Elevator System

- Space Port Station
- Geosynchronous Earth Orbit (GEO) Station
- Earth-View Station
- Tether(s)

- Ground System
  - Sea Port Station
  - Other facilities to support

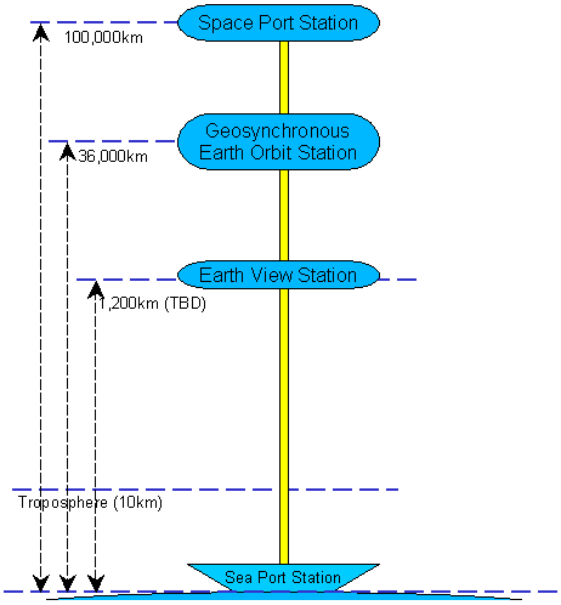

Fig. 1 Conceptual Design of the Space Elevator

After that, we described each subsystem in detail as follows:

- On-orbit Space Elevator System
  - Space Port Station, docking port for the following purpose:
    - ✧ Planetary Explorer Deployment/Retrieval
    - ✧ Transfer Vehicle from/for Moon Deployment/Retrieval
      - ✓ Get natural resources from Moon
      - ✓ Re-supply food/water/spare parts for Moon Base
  - Geosynchronous Earth Orbit (GEO) Station
    - ✧ Docking Port for Satellite Deployment/Retrieval
    - ✧ Space Solar Power System
    - ✧ Space Depot (or Intermediate Maintenance Facility): On-Orbit Repair Shop
    - ✧ Space Farm
    - ✧ Space Experiment facility
    - ✧ Space Hotel, Restaurant, Exercise Facility, Hot Spring
  - Earth-View Station
    - ✧ For the customers who want to go to space as day-trip.
  - Climber
  - Tether(s)
    - ✧ We did not talk about how many tethers are good enough to have (1) redundancy, and (2) transport capacity.
  - As an Entire On-Orbit Space Elevator System
    - ✧ Attitude/Orbit control, stabilization
    - ✧ Life Support
    - ✧ Interface with ground system/other space ship/other on-orbit system
    - ✧ Safety Inspection and Maintenance
    - ✧ Space Elevator Self-repair and re-assemble
- Ground System
  - Sea Port Station
    - ✧ Airport/Seaport for passenger/transferred products access
    - ✧ Hotel
  - Other facilities to support
    - ✧ Flight Control and Mission Plan
    - ✧ Logistics and Maintenance
    - ✧ Crew and Passenger Training
    - ✧ Space Plane Launch Site for Emergency Rescue (Might be on the Sea Port Station)
    - ✧ Threat Surveillance and countermeasure

4.3. Feasibility Study of Conceptual Design

There are many things to do as 'Feasibility Study', but we did simple estimation to evaluate how much money the Space Elevator can make so that we can evaluate our first conceptual design.

4.3.1 Draft Cost Feasibility Study

There is a result of cost estimation to transport products to GEO Station.

- Assumptions (will be in the requirement for Space Elevator)
  - A) Transport Price: 1,000 Japanese Yen/kg (9.2 Euro/kg, 11.9 US$/kg)
    (108 Yen/Euro, 84 Yen/US$ as of Sep. 4, 2010)
    (This cost is 40 times bigger than present ground transport cost in Japan.)
  - B) Payload (Products) Weight: 10 tons (Gross Weight 30 tons)
  - C) Average Climber Speed: 600km/h
  - D) Operating Rate: 90%

E) Payload load/unload duration (One way): 2 hours

- Required duration for one-way trip
  - 36000km/600km/h (e) = 60 h
  - 60H+2H (e) / 0.9 (d) = 69 h/one-way trip
- Total trip counts per year (one way)
  - 8,760 hours (1 year) / 69 h = **127 times** (of one way trip)
- Total Sales per one way trip
  - 10,000kg (b) x 1,000 Yen (a) = 10,000,000 Yen (93k Euro, 119k US$)
- Total Sales per year
  - 10,000,000 x 127 times = **1,270,000,000 Yen/Year (11.8 mil Euro, 15mil US$)**

As the 2nd cost estimation, we calculated how we can reduce electricity in case the Space Elevator helps to transfer things for Space Solar Power System (as known as SSPS) on orbit.

- Assumptions (for Rocket construction)
  - Cost estimation for constructing one 1GW class Space Solar Power System
    - ✧ Total 2,100B Jp yen (19B Euro, 25B US$)
    - ✧ 53%: Transport Cost (1,100B Jp Yen, 10B Euro, 13B US$)
    - ✧ 23%: SSPS Structure
    - ✧ 12%: Photovoltaic Solar Cell
- If we use Space Elevator, cost of transport will be 1/2000. This means we can neglect this transport. Also No need for concern of launch vibration for SSPS Structure and PV Solar Cell.
  - Total 1100B Yen (19B Euro, 25B US$)
- With Space Elevator, construction cost of SSPS will be 1000B Yen. (9B Euro, 12B US$)
- 1GW SSPS can provide 8760 GWh per year (1GW/h x 24h/day x 365 day = 8760 GWh)
- Total cost of electricity will be as follows:
  - 114 Yen/kWh/one year (at ground base) (1,000B Yen / 8760GWh = 114 Yen/kWh) (1.05 Euro, 1.35 US$)
  - If SSPS can generate 30 years without outage, it can be **3.8 Yen/kWh**. (0.035 Euro, 0.045 US$) (If use rocket, 7.9 Yen/kwh (0.07 Euro, 0.09 US$)) (Operation and Maintenance costs are not included)

According to cost estimation we performed above, there is some findings as follows:

- Products Transport
  - Transfer Vehicle's speed (i.e. Climber Speed) is relatively slow compared with distance to the GEO Station.
  - It impacts cost for transport
  - Also one Space Elevator can bring 64 x 10 = 640 tons / year / Space Elevator into GEO.

This results more than one climber must be ascending / descending at one time to conduct SSPS using Space Elevator.

5. SYSTEM REQUIREMENTS DEFINITION

5.1. Space Elevator System Requirements

Based on the Conceptual design discussion, we started to make "Space Elevator Functional Requirement Matrix" shown on Fig. 2.

Our final goal is for general passengers (not for selected Astronauts), Safety (Such as Acceleration Limit、Guest Behaviors, Terminology) is the highest requirements.

5.1.1 Gathering Study/Research of Core Technology to accomplish Space Elevator

During first year of Space Elevator Road Map development, we started to review some activities and research in Japan as follows:

- JSETEC (Japan Space Elevator Technology and Engineering Competition) [1)]
  - JSEA's Bottom Up Approach
- Bare Electro-Dynamic Tether Sounding Rocket Experiment [2)]
  - Experiments to deploy tether in Space, Top down approach
- NU Float Island Project/Nihon University
  - This technology could be used in the future for "Sea Port Station"
- Space Toilet/Earth Track Corporation
  - This technology could be used at GEO Station

6. SPACE ELEVATOR ROADMAP 2010

Based on the things which our Space Elevator study team did this year, we made draft version of Space Elevator Development Road Map 2010. (Fig. 3)

According to this Road Map, continue feasibility study and individual ley technology research and development for a while. Our target to develop Space Elevator System requirement is around 2016 - 2018. And Start demonstration on orbit will be performed around 2016 – 2030's.

<Sample of "Space Elevator Functional Requirements Matrix, Deployment/Assembly Phase>

On-orbit Space Elevator System	Mandatory	Desired	Manned	Commercial	Related Study/Research
Tether Deployment	X				Tether Sounding Rocket

<Sample of "Space Elevator Functional Requirements Matrix, Assembly Complete Phase>

On-orbit Space Elevator System	Mandatory	Desired	Manned	Commercial	Related Study/Research
Entire On-Orbit Space Elevator System	---	---	---	---	
- Attitude/Orbit control, stabilization	X?				JSETEC Tethered Balloon Experiment
- Life Support System			X		ET Space Toilet Project
- Safety Inspection and Maintenance		X?			NU Probe Climber/ Maintenance Robot
Tethers		X?			ET Vertical Linear Motor Project
Sea Port Station	X				NU Float Island Project

Fig. 2 Sample of Space Elevator Functional Requirements Matrix

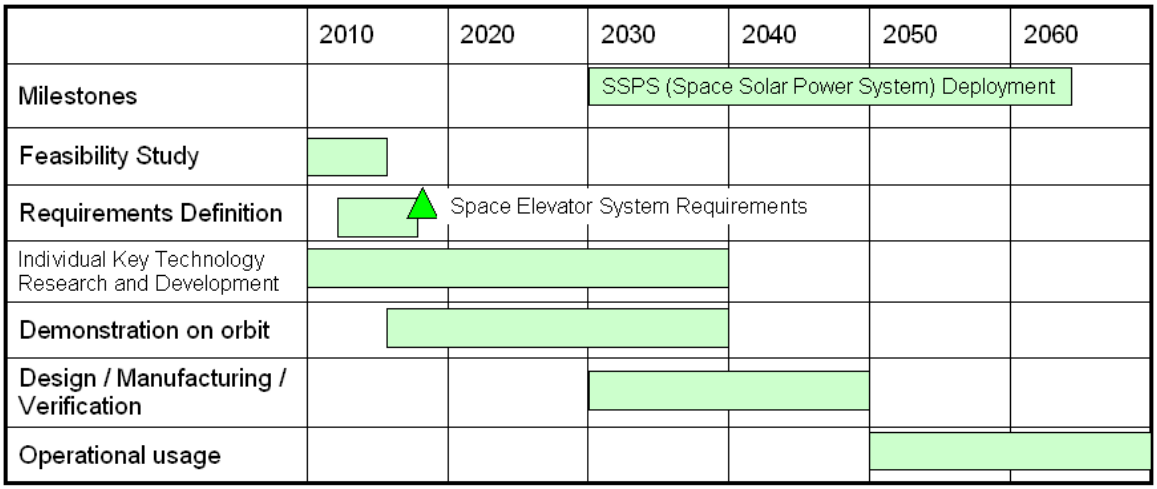

Fig. 3 Space Elevator Development Road Map 2010

If we could keep this schedule, Space Elevator can support SSPS construction to reduce transfer cost on orbit.

7. CONCLUSION

Space Elevator Development Road Map Study is just started by the members of Japan Space Elevator Association.

Annual Report will be presented at Space Elevator Conference in Japan every year.

Summary of Annual Activity will be provided at International Astronautical Congress every year.

Related study/research will be tracked and will be mapped on Space Elevator Technology Map as a part of Space Elevator Development Road Map.

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