Document 6-2
Space Development and Utilization Division,
Research and Development Bureau Roadmap Review
Meeting for Realization of Innovative Future Space
Transportation Systems (6th meeting) R3.3.3

About the Innovative Future Space Transportation System Proposal*

March 3, 2021

(National Institute) Japan Aerospace Exploration Agency

*Reference example for discussion

1. Considerations for Innovative Future Space Transportation Systems

ÿThe requirements for the space transportation system based on the study of space utilization needs assuming around 2040 are organized as follows.

	destination		
	sub-orbital orbit	Low/geostationary orbit	Deep space (Moon/Mars)
manned	•Major market proposals; P2P, space travel / transport method proposals; Vertical launch Horizontal launch	•Major market proposal; space travel and transportation method proposal; vertical launch	•Major market proposals: Moon/Mars economic zone Artemis plan (international cooperation)•Transportation method proposals: vertical launch
Unmanned	•Main market proposals: P2P, microgravity environment experiments /Transportation method proposals: Vertical launch Horizontal launch	•Proposed main market; On- orbit service security using ISS Use for disaster prevention, etc. •Proposal for transport method: vertical launch	

1. Considerations for Innovative Future Space Transportation Systems

ÿPrerequisites for system study:

(1) In Japan's space transportation development, there is no experience in developing a horizontal transportation system in the past. (In aircraft development, we also develop jet engines, ramjet engines, airframe systems, etc.)

(2) It must be a system that achieves drastic cost reduction (comprehensive system: space transport vehicle, launch site/launch facility, flight safety operation, recovery/relaunch maintenance facility in the case of reuse). To that end, it is necessary not only to propose the manufacturing costs for launches, but also to increase the number of launches using the same system (10 or more/ year).

(3) It is necessary to discuss whether the comprehensive system to be realized is singular or plural. If multiple systems are used, the number of needs that can be met increases, but there is a possibility that the benefits of cost reduction for a single system will not be fully received.

(4) It is necessary to assume that the integrated system to be realized will be applied to the private sector market in the future, and that R&D costs should be measured in terms of cost-effectiveness, taking into account the expected profit from the market and the burden on the private sector. .

2. About the Innovative Future Space Transportation System Proposal

ÿ Towards the 2040s, as a space transportation system method,

Based on the comprehensiveness of important technologies, we will introduce three reference systems, A, B, and C, extracted

from the configurations of single-stage vertical takeoff/horizontal takeoff and double-stage vertical landing/horizontal landing.

ÿ Reference system A

Flight demonstration around 2030

1st stage: Vertical take-off/vertical

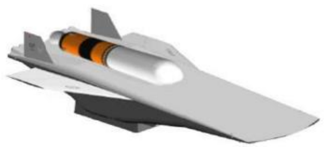
landing 2nd stage: Expendable

(Propellant: Hydrogen on the left, LNG

on the right (CN methane in the future*) * Carbon Neutral

ÿ Reference system B

Flight demonstration around 2035



1st stage: Air-breathing engine *Installed fuselage

stage: Single-use rocket ロケット

1st stage: Air-breathing engine *Installed fuselage 2nd

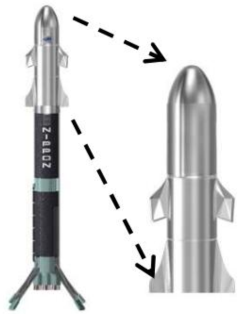
Manned loading section is attached to the 2nd stage *The air-breathing engine is

based on a rocket engine that can also access space.

combined cycle engine

ÿ Reference system C

Flight demonstration around 2040



(Development of the upper stage of reference system A) Fully reusable manned P2P specification (1 stage reusable)

Features of each system configuration

	System A Rocket type	System B winged type	System C rocket + upper stage winged
Most of the benefits including sub-orbital	Can be used for missions (can be transported to deep space)•Large onboard transport capacity (relatively easy to increase in size) •Development knowledge/accumulated related technology•Possibility of manned transport (manned capsule transport, etc.) We have a track record overseas)	•Ideal for P2P •Can share ground infrastructure such as airports •Because propellant (oxidant) can be reduced, aircraft weight can be reduced•Possibility of manned transportation (aircraft operation technology can be used)	•Available for all missions including P2P and sub-orbital (transportation to deep space is possible)•Explore development knowledge/ accumulated related technology for the rocket part (low technology maturity for the upper part)•Manned transportation possibility
Disadvantages : Limited firing range	•Lighter airframes, higher engine performance •New equipment and maintenance such as sea recovery •P2P is not supported	•It is difficult to transport a large structure on orbit or to deep space by itself (exceeds the realistic size of the aircraft and requires a long-distance landing site) •Currently, the main technologies (engine, thermal structure) technology maturity is low (requires integration with the aviation sector)	•The on-board transport capacity is relatively low compared to the rocket type (relatively easy to increase in size) •Currently, the technology maturity level of the main technologies related to upper stage reuse (lightweight thermal structure, re-entry guidance) is low

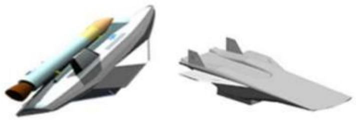
Significance and value of reuse (common) • Respond to high-frequency launches • Increase opportunities for high-frequency improvement development due to high-frequency launch opportunities (utilization of new and old simultaneous flights, etc.) • Safety and reliability for unmanned / manned transportation premature maturation of sex

Reference system example

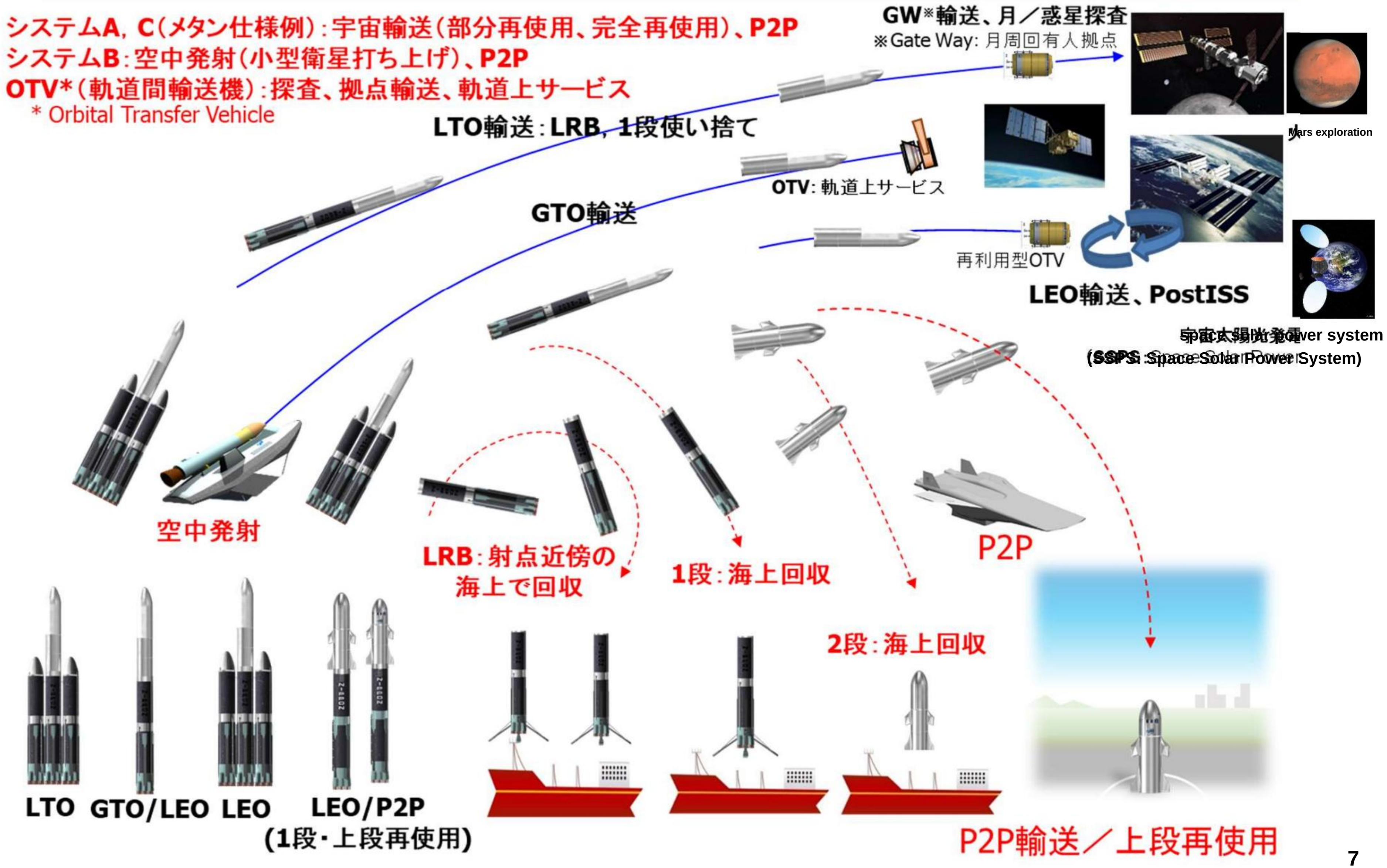
System realization

scenario (example) • Realize partial reuse (system A) around 2030, accelerate R&D and flight demonstration for upper stage reuse, and realize system C by 2040. •Regarding System B,

TRL (Technology Readiness Level) is low .

システム	システムA:ロケットタイプTSTO※ (部分再使用検討例) ※Two Stage To Orbit		システムB:有翼タイプTSTO※ ※Two Stage To Orbit	システムC:ロケットタイプTSTO※ (完全再使用)※Two Stage To Orbit
機体イメージ				
打ち上げ能力	シングル スティック 【一段再使用】 LEO 15 ton GTO 4.2 ton 【一段使い捨て】 LEO 20 ton GTO 6.8 ton	LRB2基形態 【一段/LRB※再使用】 LEO 26 ton GTO 8.1 ton 【一段/LRB※使い捨て】 LEO 54 ton GTO 21 ton LTO※※ 16 ton ※:Liquid Rocket Booster 補助ロケット ※※:Lunar Transfer Orbit 月遷移軌道	SSO 300kg(TBD) P2P(有人輸送):10数名(TBD)	ファミリー化にて広レンジに対応 上段はサブオービタル利用にも発展 能力はTBD.
ミッション要求(案)	• 打上費目標:TBD • LRB射点回収,コア海上回収 • LRB再使用回数:8〜10回 • 再整備期間:20〜40日間 • 有人輸送:TBD		• 打上げ費用:TBD • 再使用回数:TBD • 再整備期間:TBD • 有人輸送:TBD	• 打上費目標:LEO1~2億円/ton以下 • 再使用回数:8〜10回 • 再整備期間:20〜40日間 • 有人輸送:3人以上のクルーをLEOとP to P輸送できる発展性を有すること
主な技術課題	下記に資する低コスト化技術が必要 ✓ モデルベース開発の高度化・低コスト化 ✓ 主構造タンク複合材化 ✓ 共通隔壁化 ✓ 軽量降着装置 ✓ 点検・再整備技術 ✓ AM適用範囲拡大	✓ 各部電動化 ✓ 無効推薬を減らす推薬管理 ✓ 完全自律飛行安全 ✓ 機器統合 ✓ ワイヤレス化 ✓ 洋上回収システムなど	✓ モデルベース開発の高度化 ✓ 複合材技術 ✓ ヘルスマネジメント技術 ✓ 有人化技術 ✓ エアブリージングエンジン技術 ✓ 耐熱・熱制御技術 ✓ エアブリージングエンジンでの機体設計技術 など	✓ システムAの技術課題に加えて ✓ 有人発展性技術 ✓ 上段再使用化技術 ✓ 環境保全技術 ✓ 着陸環境整備 など

Usage image and system around 2030-2040



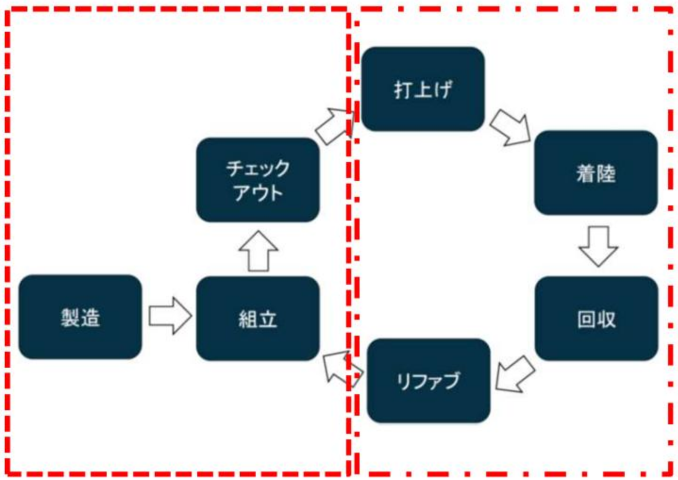
3. Cost reduction measures for fundamentally low cost

ÿ Reuse of transportation systems

ÿThe **launch and transportation cost of a completely reusable system is estimated as follows, and it is necessary to reduce manufacturing costs, launch costs,** maintenance costs, and increase the number of uses.

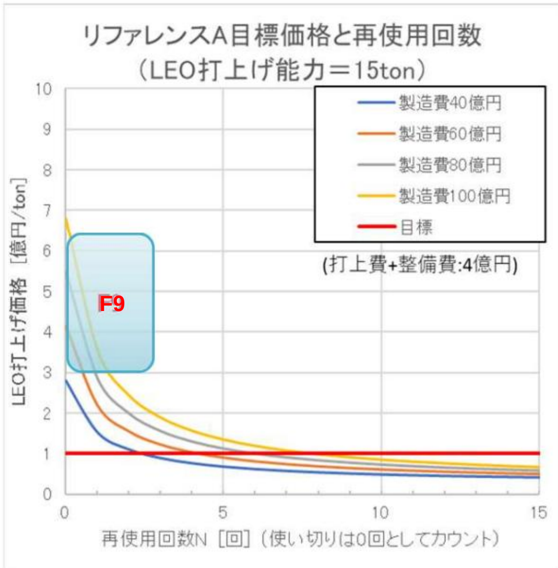
{(Manufacturing cost) + (Launch cost) x (Number of uses) + (Maintenance cost) x (Number of uses - 1)} ÷ (Number of uses)

ÿ **However, the effect of reducing launch transportation costs by reusing the aircraft will decrease after a certain number of times. Since there is a possibility that development, manufacturing, and maintenance costs will increase, it is necessary to determine the number of times of reuse while setting the launch price in stages based on market demand.**

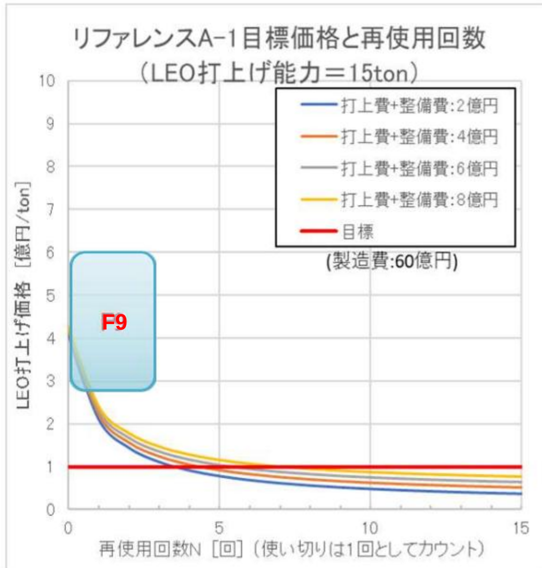


manufacturing cost

Operating expenses



Manufacturing cost (including propellant) sensitivity to reuse count (LEO launch capacity 15ton)



Operating cost sensitivity to reuse count

(LEO launch capacity 15 tons) *Example

8: Manufacturing cost: 6 billion yen (launch price 400 million yen/ton)

3. Cost reduction measures for fundamentally low cost

ÿCost reduction of parts, materials, etc. (common use of ground parts, general-purpose materials, etc.)

In the space transportation system so far, except for the application of some in-vehicle products, parts are basically purchased according to aerospace specifications such as MIL-SPEC. For this reason, they tend to be more expensive than general distribution products, with additional costs such as inspection costs. We will change these to JIS standards and other market standard specifications that are in high demand, and reduce costs by addressing system design such as redundancy to ensure reliability. Based on the carbon neutral policy, it is

assumed that the market for composite materials will expand and the cost will go down.

Therefore, the scope of application of the composite material will be expanded, and the cost including the manufacturing

method will be reduced. ÿInnovation of manufacturing process (3D printing technology, model-based development, labor saving in actual testing, etc.)

•In 3D printing technology, it is important to shift from design technology based on conventional manufacturing technology such as machining to topology design that optimizes functions and costs. We use digital twin technology for these design technologies to create more efficient and low-cost products. We will further promote model-based development to realize efficient development, not only to realize low-cost products, but also to reduce the scale of actual tests and inspections.

* Digital Ruin technology: Virtually reproduces the airframe and mechatronics on a computer to improve efficiency and value in all phases of concept development, design, production, and use.

ÿInternational cooperation (procurement/technical cooperation)

Regarding common products of domestic space transportation operators and foreign space transportation operators,

Procurement of products that do not require development and maintenance costs, promote technical cooperation, and reduce launch costs.

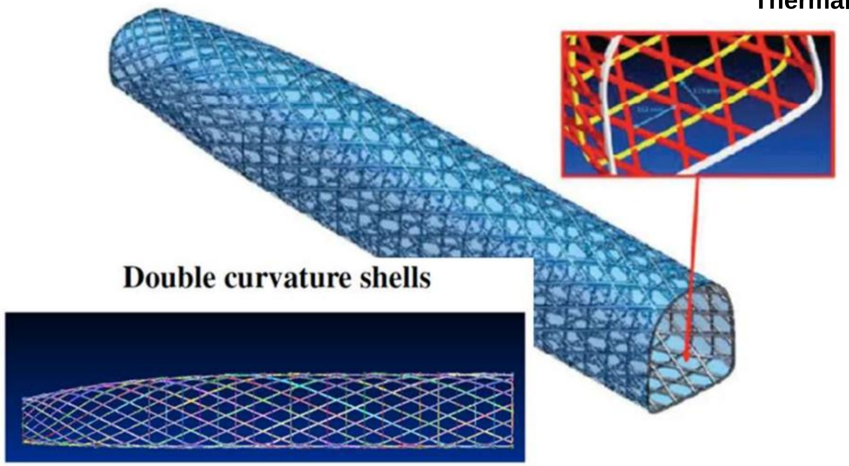
Examples of expanding the application range of low-cost composites

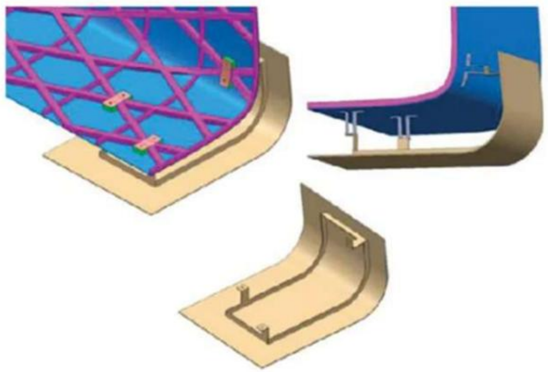
【3次元曲面形状への適用性】
再使用型上段機体でも使い捨てでも必ず必要になる3次元曲面形状への適用性はCFRPが優れている。
（金属材料から切削加工で製造すると材料の無駄が多くなり高コスト）

宇宙機に限らず、航空機の胴体構造にもCFRPラティス構造による3次元曲面形状のニアネット製造適用の検討事例があり。

【スタンドオフTPSとの構造結合への適用性】
大型複曲面構造にラティスを用いることで、リブ交点をハードポイントとしたTPSインタフェース適用性も良いと期待される。

*** Thermal Protection System: Thermal protection system**

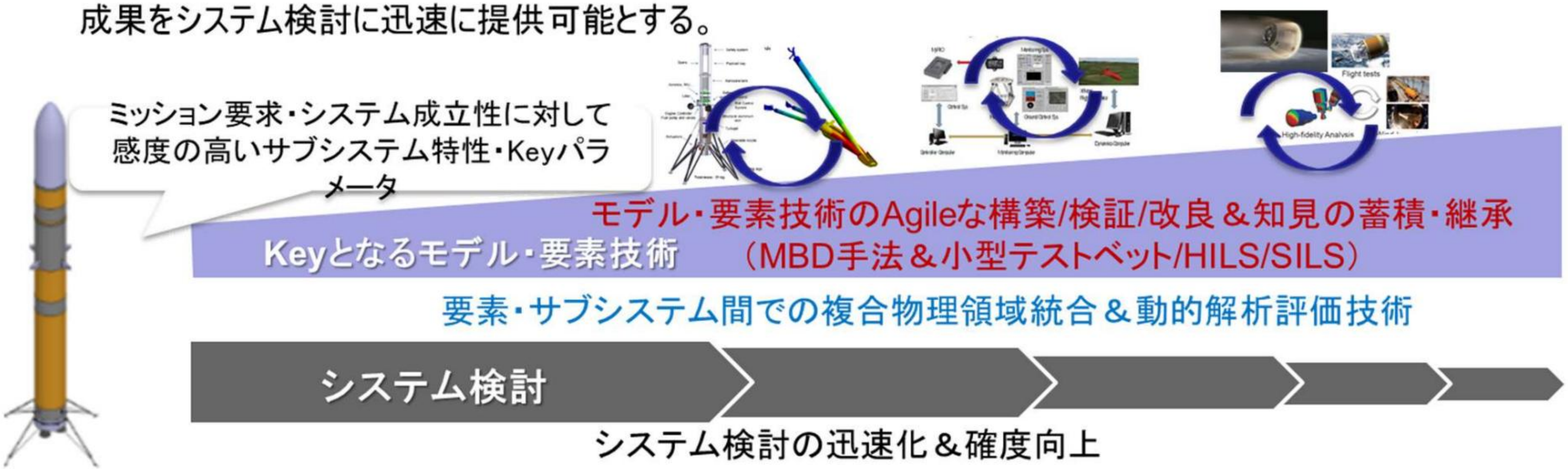


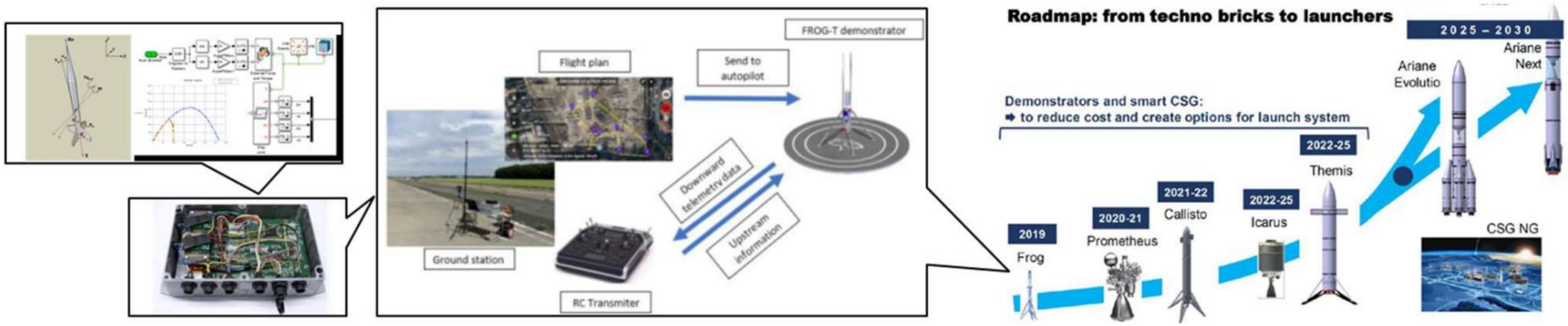


Applying model-based development (MBD) to systems

■ MBD基盤構築

開発期間の短縮・スピード向上を目指し、システム成立性のKeyとなるモデル・要素技術を小さく・短期(Agile)に構築/検証/改良するための仕組み(小型テストベット/HILS/SILSの活用等)を構築し、最新の成果をシステム検討に迅速に提供可能とする。





小型テストベットを活用したモデル・要素技術のAgileな検証

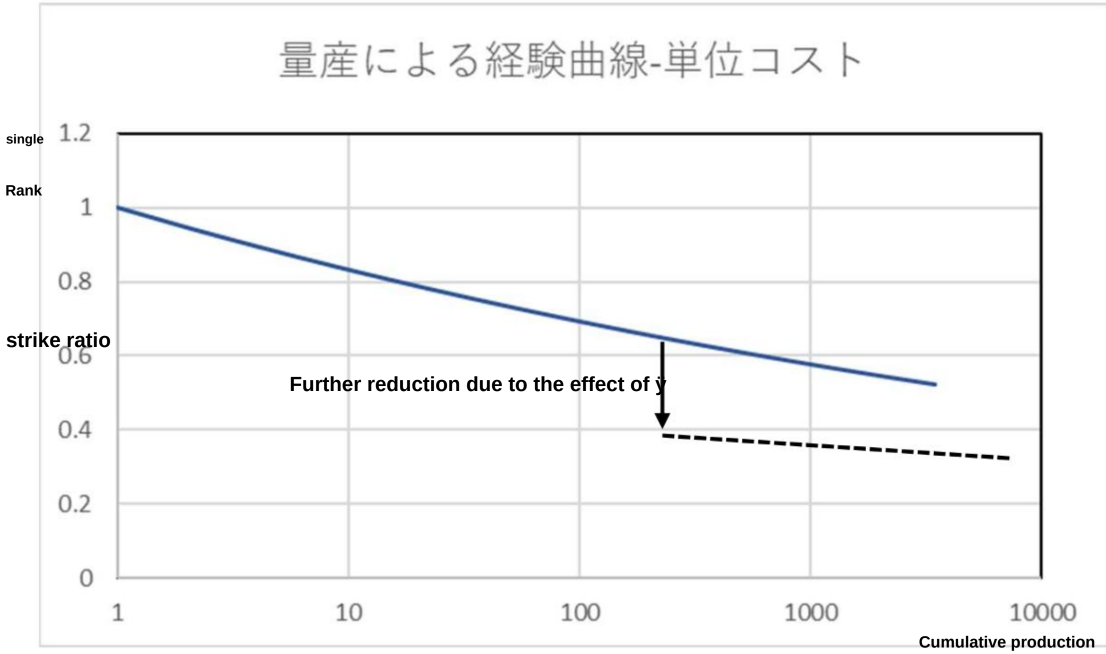
3. Cost reduction measures for fundamentally low cost

ÿIncrease in number of

launches (mass production effect)

may have a productive effect. The effects of mass production are: ÿ reduction in fixed costs (equipment maintenance costs required for manufacturing, etc.); There are equipment scale up, automation and efficiency improvement based on equipmen

*** Space X significantly shortens the turnaround time by repeating the reuse operation of the first stage. The turnaround time required for the first reuse was about 350 days, but it has been shortened to about 40 days in recent launches.**



volume experience curve: unit cost = initial production unit cost x (cumulative production volume) ^ (cost elasticity with respect to cumulative production volume)