第2回革新的将来宇宙輸送システム実現に向けたロードマップ検討会

資料 2-2-1
研究開発局宇宙開発利用課
革新的将来宇宙輸送システム実現に向けたロードマップ検討会
（第２回）R2.12.2

東京理科大学発ベンチャー
SPACE WALKERの将来展望

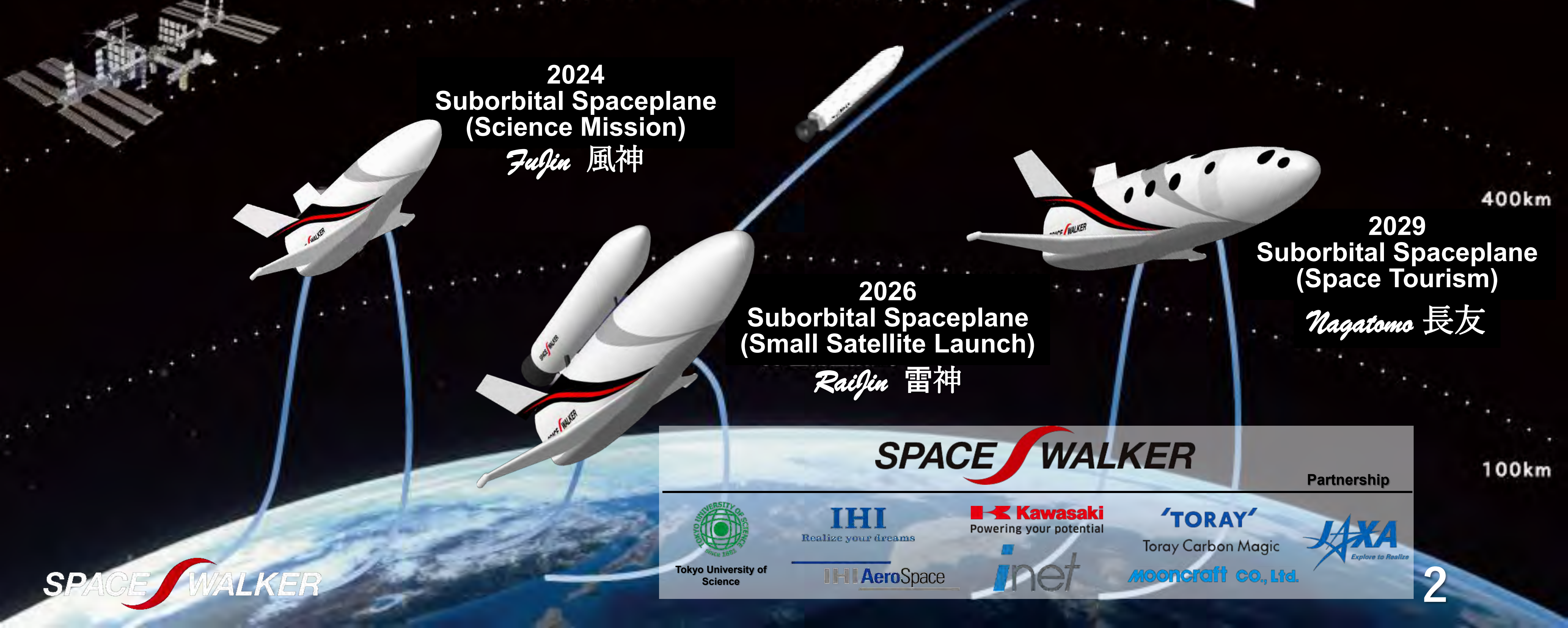
1．SPACE WALKERの取り組み
2．商業サブオービタルスペースプレーンの市場
3．宇宙輸送の抜本的コスト削減と技術課題
4．SPACE WALKERが描く将来宇宙輸送ビジョン
5．産官学の役割分担と期待

2020年12月2日

SPACE WALKER

1．SPACE WALKERの取り組み

「宇宙が，みんなのものになる。」をスローガンに，メイド・イン・ジャパンのサブオービタルスペースプレーンを産官学パートナーシップ（オープンイノベーション）で実現



■我が国が1980年代から培ってきた再使用型宇宙輸送技術研究と大学の先進的基礎技術研究を結集

1970's	1980's	1990's	2000's	2010's	2020's

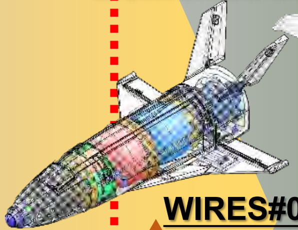
HIMES
(HIghly Maneuverable Experimental Space vehicle)
1980's
ISAS (Ministry of Education)

HIMES is the Roots of Suborbital Spaceplane

HOPE/HOPE-X
(H - II Orbiting PlanE eXperimental)
Mid 1980's ～ Beginnings of 2000's
National Aerospace Lab. / Space development Agency

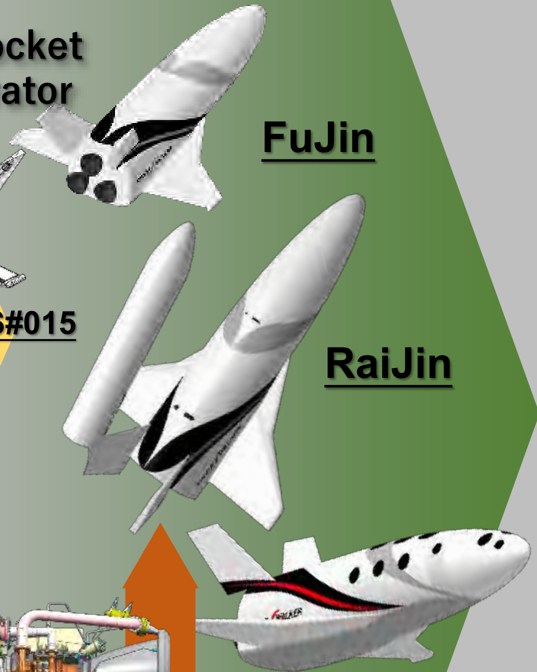
WIRES
(Winged REusable Sounding vehicle)
2005 ～
Tokyo University of Science (Kyushu Institute of Technology)

Winged Rocket Demonstrator



WIRES#015

Suborbital Spaceplane
(Space Walker Inc. & Partners)

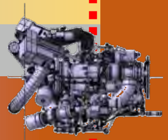


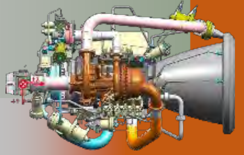
FuJin

RaiJin

NagaTomo

LNG (Liquefied Natural Gas) Engine Development
2013 ～
JAXA (Japan Aerospace Exploration Agency) and IHI Collaboration



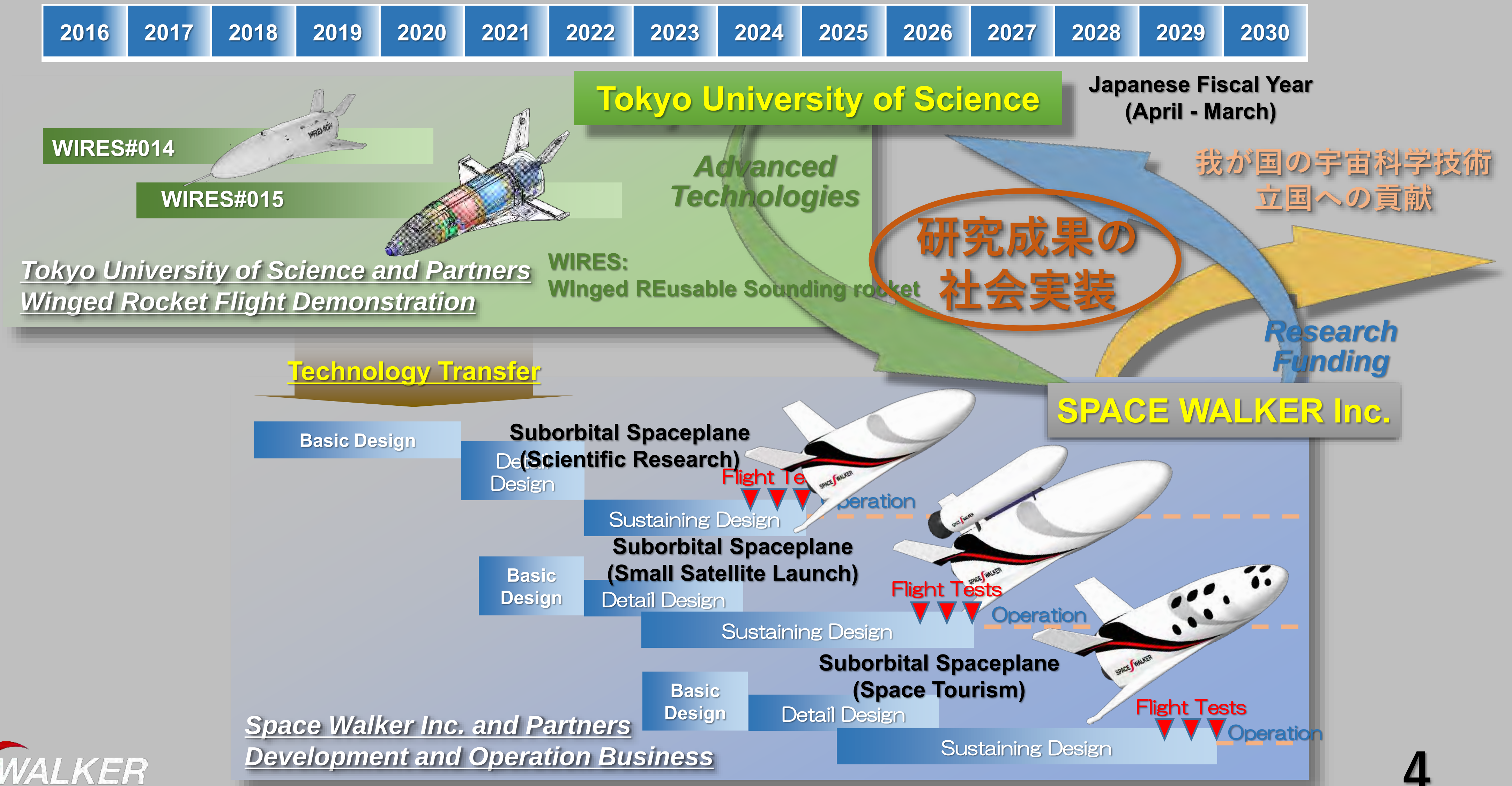


LOX-Methane Engine (IHI In-house Development)

SPACE WALKER

1．1　全体開発計画

大学の基礎研究と産官学パートナーシップで行う飛行実証成果を商業宇宙輸送事業に応用



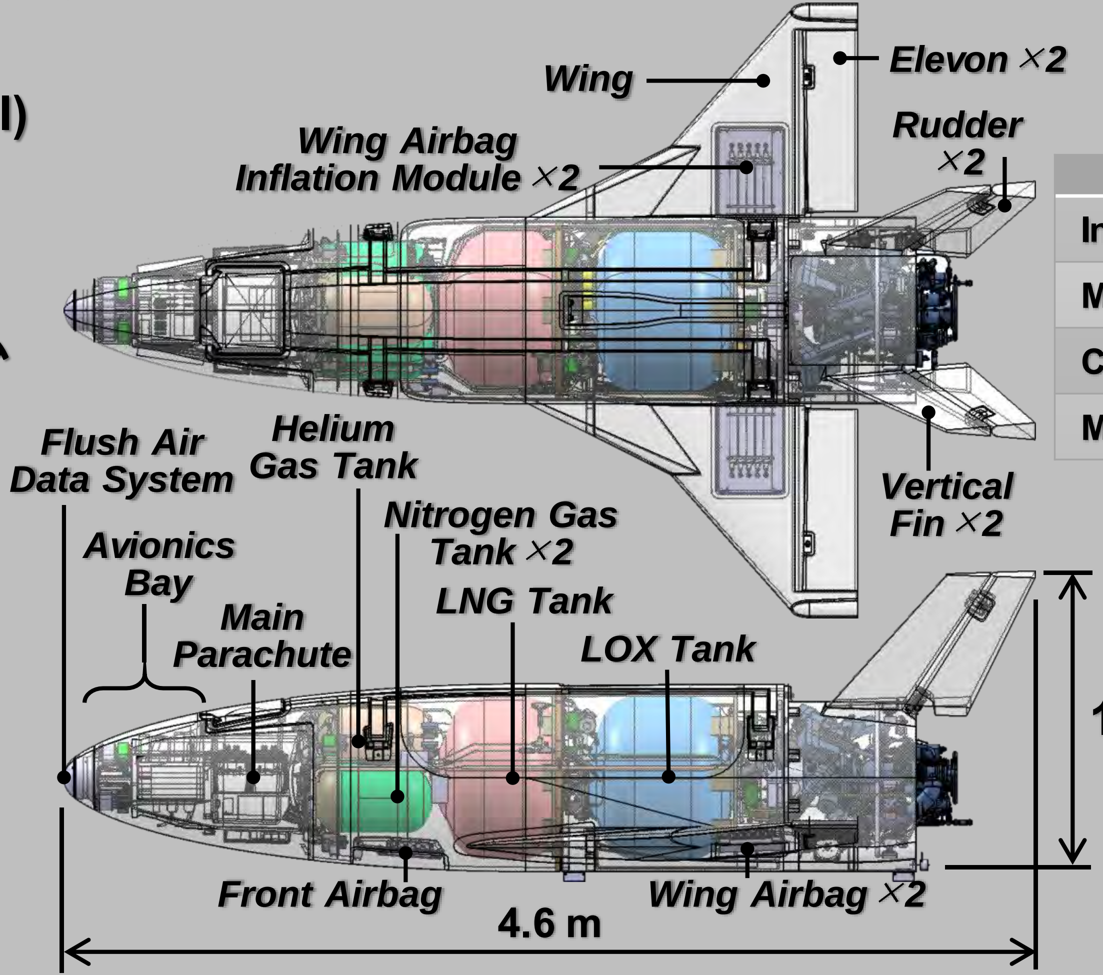
SPACE WALKER

１．２　有翼ロケット実験機WIRES#015による飛行実証実験

- 東京理科大学とJAXA研究開発部門との共同研究
- ドイツ航空宇宙研究センターDLRとの連携により2022年夏期と2023年春期にスエーデン Esrangeにて実施の計画（2021年夏期に北海道大樹町にてヘリコプターを使った予備実験）

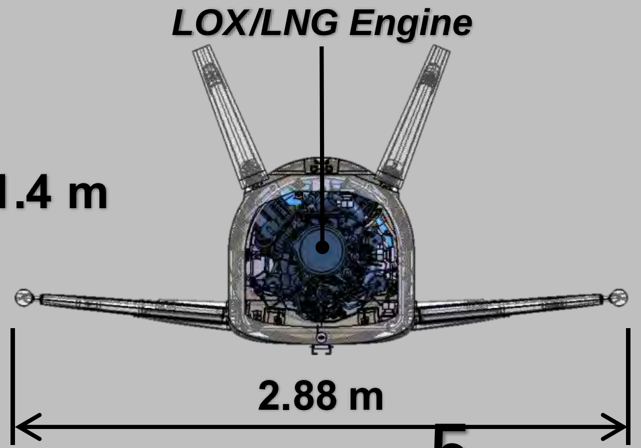
実証技術

- ➢ LOX/LNG エンジン (JAXA/IHI)
- ➢ 航法誘導制御技術
  - / DI理論を用いた環境適応型非線形制御
  - / 進化計算によるリアルタイム最適軌道生成と軌道誘導
- ➢ 複合材製極低温燃料タンク
  - / LNGタンク
  - / LOXタンク



WIRES: WInged REusable Sounding vehicle

Major Specifications		
Initial Mass	1,000	[kg]
Max. Thrust	17.8→13	[kN]
Combustion Time	30	[s]
Max. Altitude	6	[km]



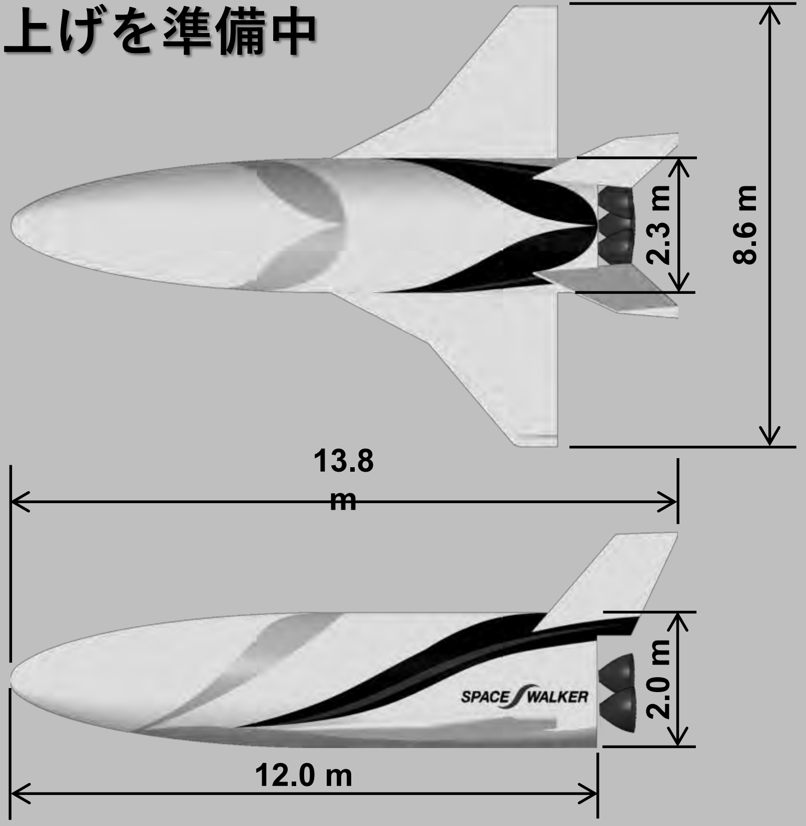
＜参考＞
山崎彩花他，「有翼ロケット実験機WIRES#013およびWIRES#015の詳細設計状況について」，1I06，第64回宇宙科学技術連合講演会，2020年11月.

SPACE WALKER

Sweden/Kiruna ESRANGE

1．３　サブオービタルスペースプレーンFuJin（「風神」：科学ミッション）の開発

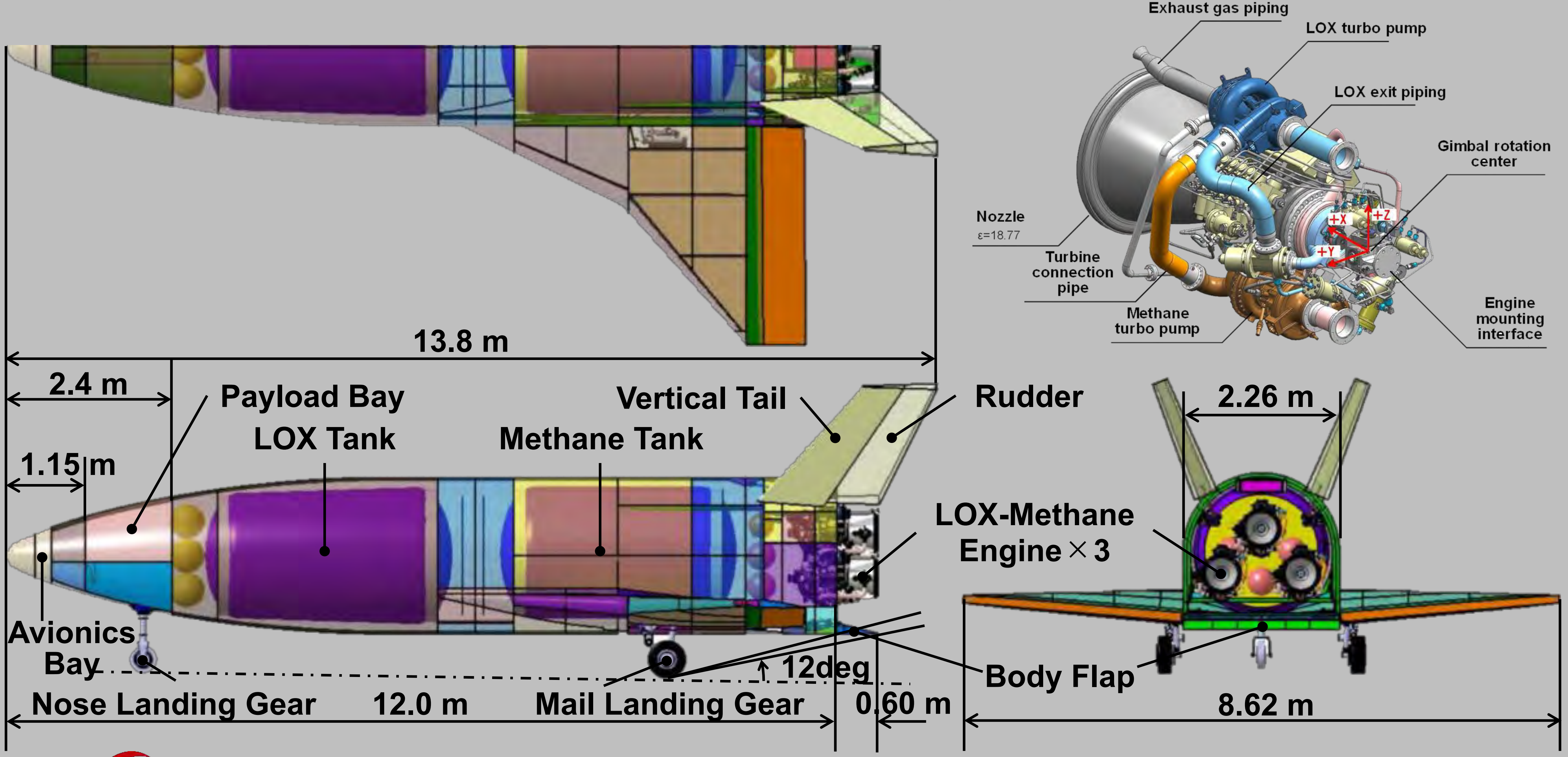
- 基本設計の最終段階にて規模策定を完了し，詳細設計の立ち上げを準備中



Structure	Wing	694
	Fuselage	916
	Tail	213
	Body Flap	77
	Tank Skirt	60
	Thrust Structure	154
	Thermal Protection System	218
Propulsion Systems	Engine	683
	Equipment	879
	RCS	16
Propellant Tanks	LOX	136
	Methane	130
	GHe	16
	GN2	73
	GN2 (RCS)	164
Mechanical Equipments	Landing Gear	263
	Actuator (Elevon, Rudder, Body Flap)	145
	Miscellaneous	15
Electrical Equipments	Computer	14
	Wire Harness	51
	Battery etc.	248
Payload		100
Margin		775
Total Empty Mass		6,039
Fuel	Filled Fuel	12,198
	Residual Fuel	503
Initial Lauch Mass		18,237
		Unit: kg

＜Ref.＞　Yonemoto, K,T., “Preliminary Design Status of Unmanned Suborbital Spaceplane with LOX/Methane Engines by Tokyo University of Science’s Start-up with the Partnership of Industries: Part 2”, IAC-20,D2,4,9,x59725, 71st IAC, 12-14 October 2020.

SPACE WALKER


Exhaust gas piping
LOX turbo pump
LOX exit piping
Gimbal rotation center
Nozzle
ε=18.77
Turbine connection pipe
Methane turbo pump
Engine mounting interface
13.8 m
2.4 m
1.15 m
Payload Bay
LOX Tank
Vertical Tail
Methane Tank
Rudder
2.26 m
LOX-Methane Engine × 3
Avionics Bay
12deg
Body Flap
Nose Landing Gear
12.0 m
Mail Landing Gear
0.60 m
8.62 m

運航は，北海道広尾郡大樹町多目的航空公園で計画中のスペースポートの射点と滑走路（場外離着陸場）の利用を計画中

国土交通省（航空局長）
「地方航空局における場外離着陸許可の事務処理基準」
＊進入表面のこう配は20分の1以下し，同表面の上に出る高さの物件がないこと

2．商業サブオービタルスペースプレーンの市場

■科学ミッション
- Basic and Applied Research
- Aerospace Technology Test and Demonstration

■小型衛星打上
- Quick and Frequent Turn-around Operation

■宇宙旅行
- Earth Sight Seeing
- Micro-gravity Experience

＜Ref.＞　“Space Tourism and Travel Market”, NSR, Dec. 2019.

Suborbital Industry Markets

	Opportunities	Challenges
COMMERCIAL HUMAN SPACEFLIGHT *Human spaceflight experiences for tourism or training*	• New and unique offering • More affordable, easier access to space • May lead to long-term applications, like adventure sports	• High costs • Real and perceived safety risks
BASIC AND APPLIED RESEARCH *Basic and applied research in a number of disciplines, leveraging the unique properties of and access to the space environment and microgravity*	• Access to space • Quality microgravity of meaningful duration • Frequent flight opportunities • Prices within important funding thresholds • Broad range of feasible experiments - Payload recovery - Large payloads - Humans and equipment together - Sensitive equipment and instrumentation	• Duration of time spent in microgravity is not suitable for all types of space research • Frequency of flight opportunities not sufficient for all research objectives • Still expensive, with limited access, compared to most non-space research environments
AEROSPACE TECHNOLOGY TEST AND DEMONSTRATION *Aerospace engineering to advance technology maturity or achieve space demonstration, qualification, or certification*	• Suborbital space qualification and testing can reduce cost and accelerate TRL advancement • Overcomes “chicken & egg” problem of space qualification and demonstration • Potential value to all space organizations • Micro-/nano-satellite launch • More hands-on space project management	• Suborbital provides important, but limited analog to orbital environment • Extensive terrestrial test facilities exist
REMOTE SENSING *Acquisition of imagery of the Earth and Earth systems for commercial, civil government, or military applications*	• Resolution/field-of-view niche between aerial and satellite • Safe and responsive intelligence, surveillance, and reconnaissance • Micro-/nano-satellite launch	• Limited locations • Robust capabilities of existing systems - Aerial and satellite for civil and commercial markets - Satellite and UAV for military applications (also new ISR rocket in development)
EDUCATION *Providing opportunities to K-12 schools, colleges, universities, and graduate programs to increase access to and awareness of space*	• Allows graduate students timely, predictable data • Within K-12 and undergraduate education budgets	• Competing with other education priorities • K-12 spending has tight upper limits per school • Integration with state and federal testing and required curricula • Reliance on availability of secondary and tertiary payloads may limit opportunities and control
MEDIA AND PUBLIC RELATIONS *Using space to promote products, increase brand awareness, or film space-related content*	• Space images and associations have appeal • Small existing market for video on parabolic flights	• Scheduled events required in advance for promotion and planning • Limited audience for space launches • Commercial launches to date have not attracted substantial or mainstream advertising • In-space filming competes with CGI animation for low cost and flexibility
POINT-TO-POINT TRANSPORTATION *Future transportation of cargo or humans between different locations*	• Reduced air-time for transportation of cargo or humans	• Infrastructure and vehicle development required • Uncertainty about regulatory requirements • Global overnight possible with “merely” supersonics • Air-time not the driver of total travel time

＜Ref.＞　The US Commercial Suborbital Industry: A Space Renaissance in the Marking, U.S, Dept. of Transportation & FAA, 2011.

SPACE WALKER

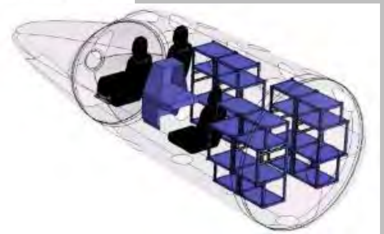
２．１　科学ミッション

■Virgin Galactic Spaceship2

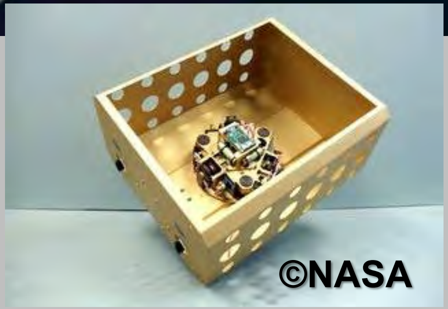

GALACTIC Payload Users' Guide

This document does not contain technical data whose export is restricted by the Arms Export Control Act (Title 22, U.S.C. Sec 2751 et seq.) or the Export Administration Act of 1979, as amended (Title 50, U.S.C., App. 2401, et seq.). This document has been approved by Virgin Galactic for public release.

Revision Number: WEB002
Release Date: 12 December 2011



Virgin Galactic President Mike Moses and Gen. Stefano Cont sign a contract Oct. 2 for a SpaceShipTwo flight for the Italian Air Force. Credit: SpaceNews/Jeff Foust



<Ref.> 1. “Virgin Galactic Spaceship Offers Enticing Science Opportunities,” space.com, July 19, 2013.
2. “Virgin Galactic to fly Italian Air Force research mission,” Space News, Oct. 2, 2020.
3. “NASA Selects First Human-tended Suborbital Research Payload,” Space News, Oct. 14, 2020.

■Blue Origin New Shepard

©Blue Origin

On Oct. 10, 2020, New Shepard with $1.5 million NASA-financed science experiments (terrain relative navigation etc.) as well as experimental cargo from private companies vehicle has launched and landed seven times at a test site near Van Horn, Texas.

The company is finding a more modest business in the short term: turning the reusable New Shepard rocket and capsule into an effective, and profitable, platform for testing new technologies and performing scientific experiments.

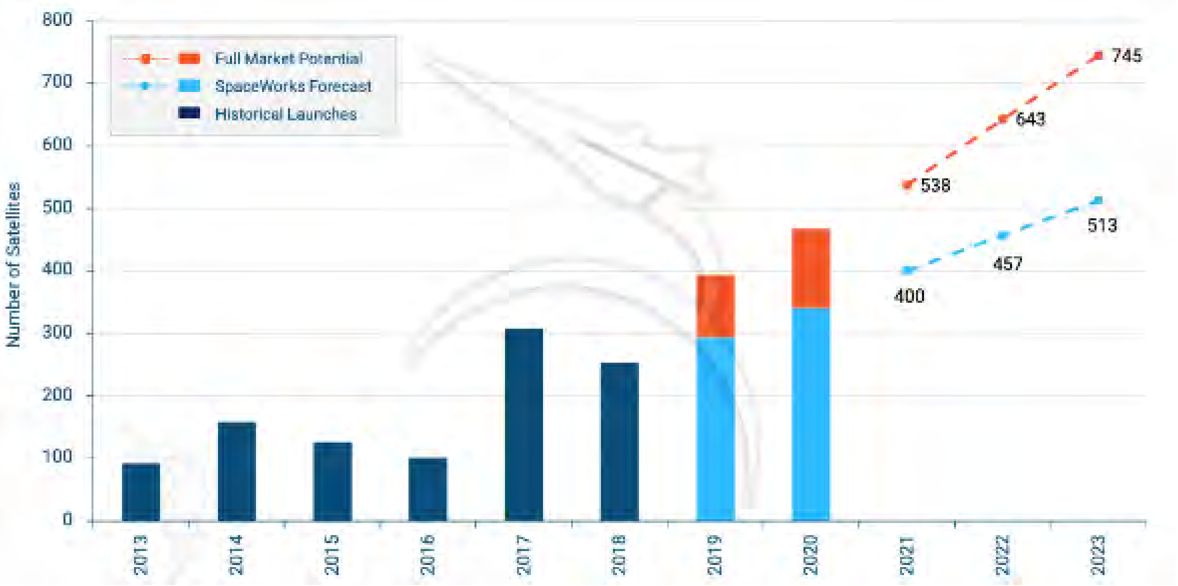
That starts around $100,000 for about 25 pounds, but many payloads for students as low as $8,000.

©Blue Origin

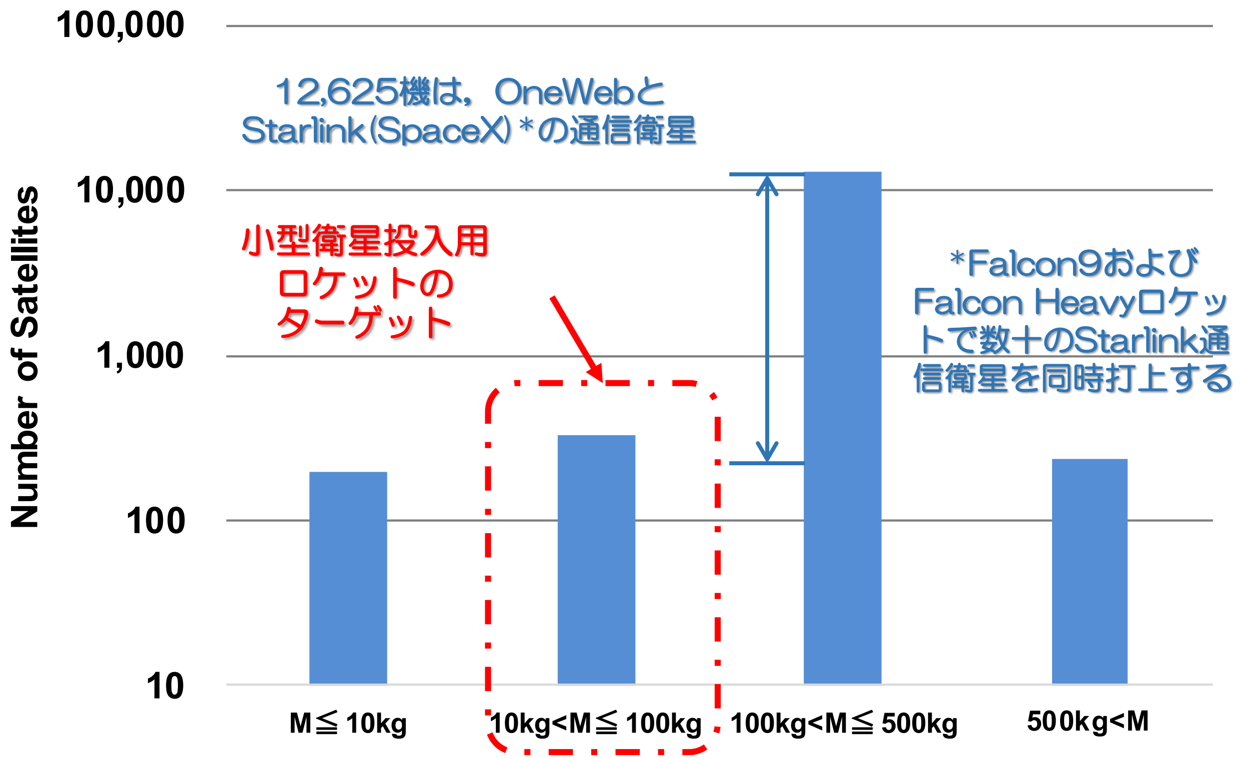
<Ref.> "Jeff Bezos' Company Is Carrying Scientific Cargo to Space. It's Not Amazon," The New York Times, Oct. 19, 2020.

2．3　小型衛星打上

SATELLITE LAUNCH HISTORY & MARKET FORECAST
Nano/Microsatellites (1 – 50 kg)
*** SpaceWorks estimates 2,000 – 2,800 nano/microsatellites will require launch over the next 5 years**

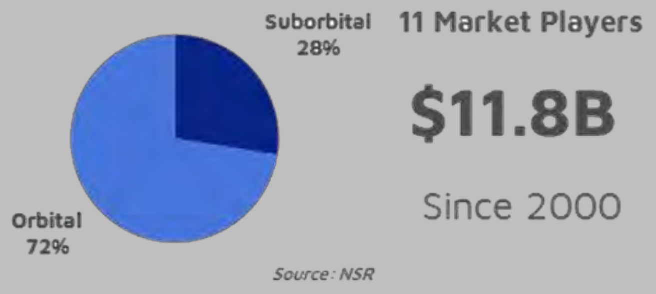


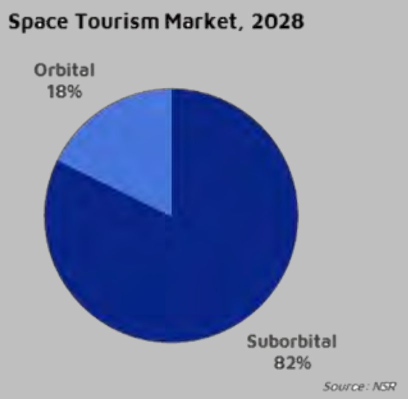
＜Ref.＞ SpaceWorks 2019 Nano/Microsatellite Market Forecast, 9th Edition.

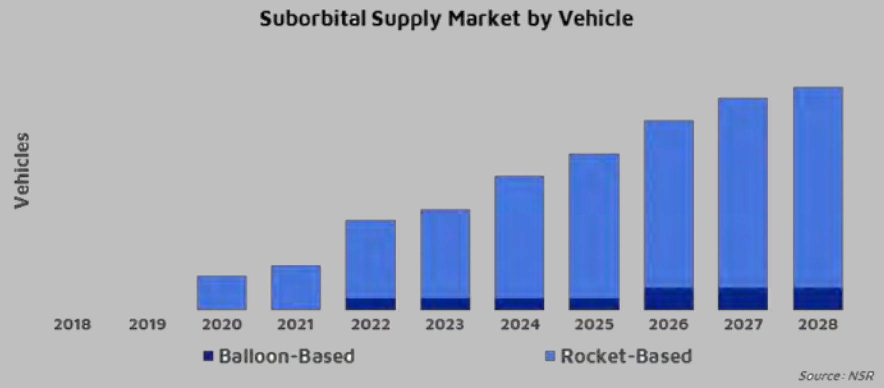


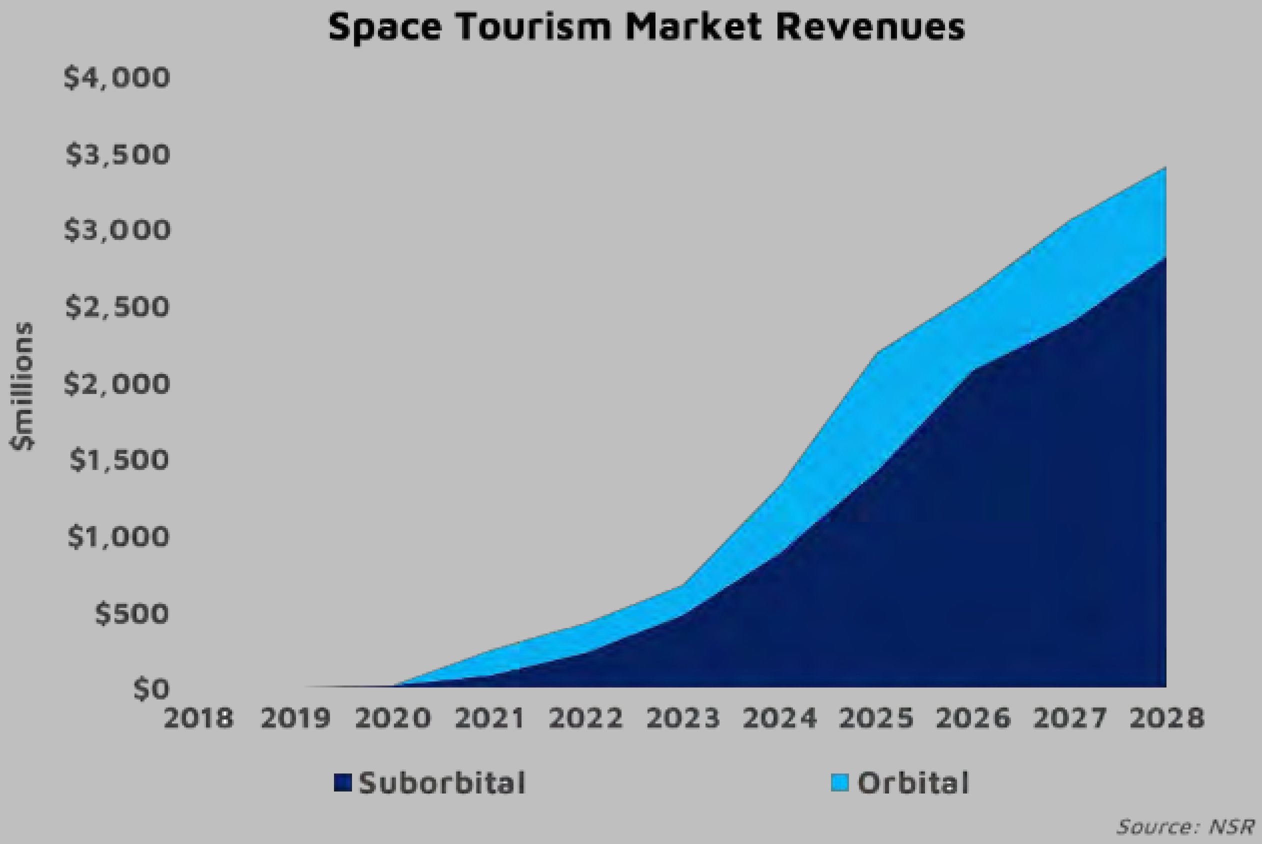
２．３　宇宙旅行

By 2028, MSR(Northern Sky Research) expects suborbital will be a $2.8 billion market, with $10.4 billion in total revenue over the next decade, while orbital will be a $610 million market, with $3.6 billion in total revenue over the next decade.









＜Ref.＞　"Space Tourism and Travel Market", NSR (Nouthern Sky Research), Dec. 2019.

Suborbital

- ✓ Virgin Galactic has sold about tickets to about 600 passengers at a price between $200,000 and $250,000 each.
- ✓ Blue Origin has said its ticket pricing is yet to be determined, but the flight price will be comparable to competitors.

Orbital

SpaceX hasn’t disclosed specifically the current contracts are worth, but previously announced that it will likely cost about $50 million per person to fly with Crew Dragon.

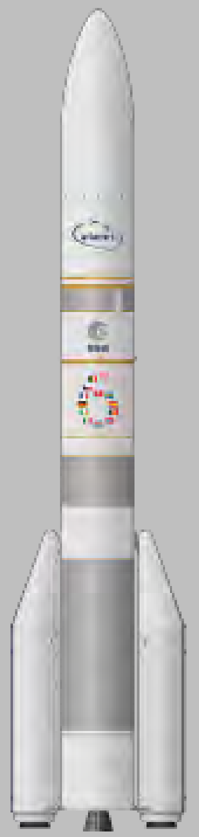

©Virgin Galactic


©SpaceX

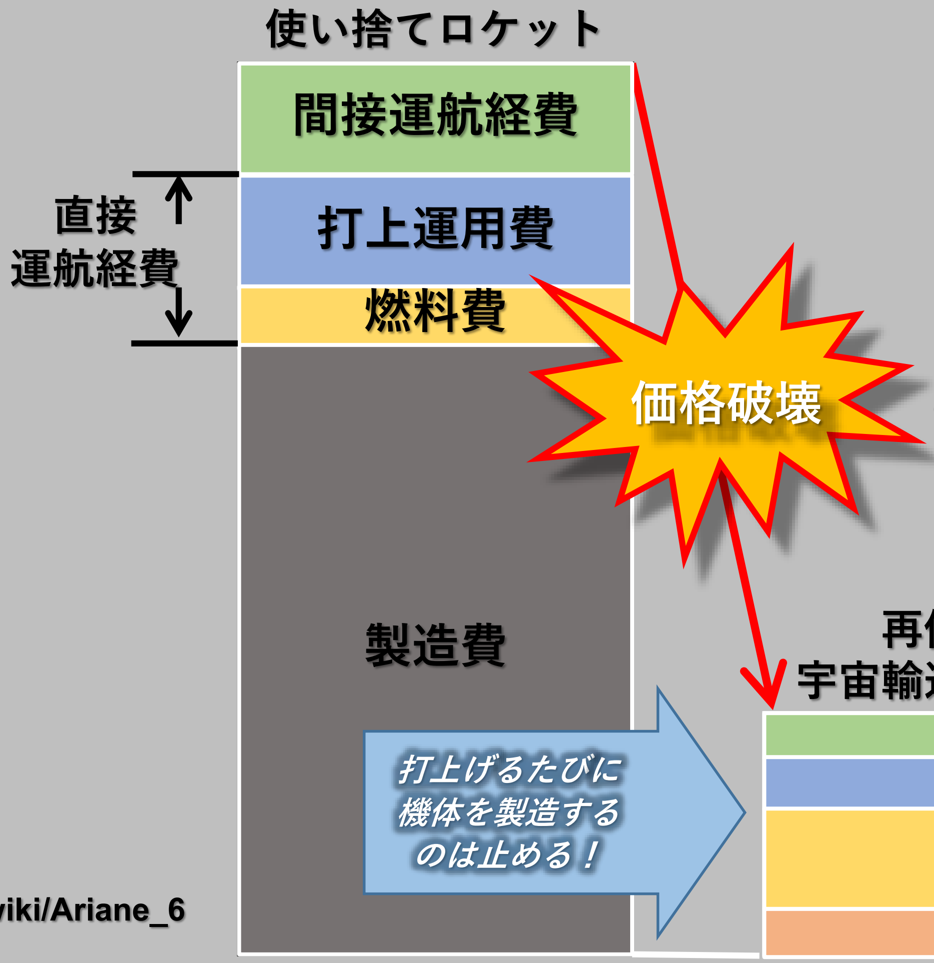
３．宇宙輸送の抜本的コスト削減と技術課題

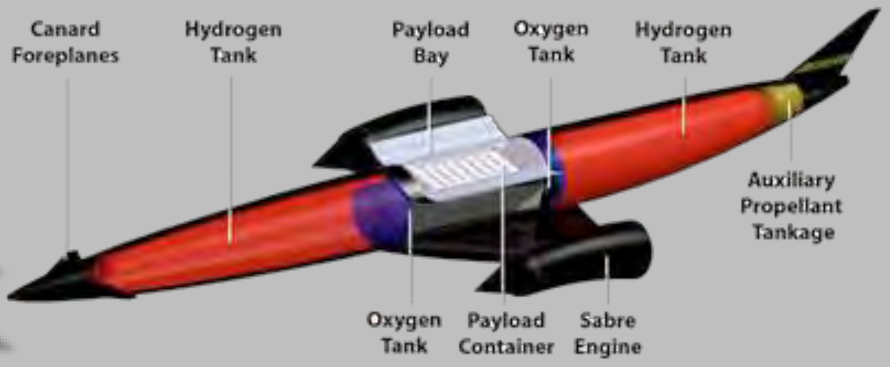
３．１　再使用型宇宙輸送システム

宇宙輸送の抜本的コスト削減は，<u>航空機のように高頻度で繰り返し利用される再使用宇宙輸送システムの実現</u>にある.



https://en.wikipedia.org/wiki/Ariane_6





https://en.wikipedia.org/wiki/Skylon_(spacecraft)

SpaceX
Falcon 9 Reusable

Rocket Lab
Electron

Ariane Next C600-C126
configuration
equipped with recovery kit

©Arian Group

＜Ref.＞
1. Antoine Patureau de Mirand et.al., “Ariane Next, a vision for a reusable cost efficient European rocket”, NSR (Nouthern Sky Research), DOI: 10.13009/EUCASS2019-949, 8th EUCASS, 2019.
2. 「SpaceXが初めて2つのフェアリングの回収に成功、再利用で1回の打ち上げにつき約6.4億円節約に」, TechCrunch,July 21, 2020.
3. “Rocket Lab on road to reusability after successful booster recovery,” space.com, November 25, 2020.

SPACE WALKER

3．2　技術課題

宇宙輸送システムの開発は，高度なシステムインテグレーション技術が必要である．航空機と同様に高頻度で繰り返し利用可能な再使用型宇宙輸送システムとしてのサブオービタルスペースプレーンの実現に向けて，SPACE WALKERが取り組んでいる技術課題は，以下の通りである．

技術		課題
1	故障許容システム	・誘導制御，構造，推進系，機械装備，電気装備，地上間通信等までを俯瞰した故障許容システムの構築
②	LOX/LNGエンジン	・再使用性/寿命管理設計 ・ヘルスモニタリング ・推力制御機能 ・緊急停止と再起動能力
③	自律航行	・故障許容航法システム ・リアルタイム最適軌道生成と経路誘導 ・環境適応型姿勢制御技術
4	複合材製機体構造	・炭素繊維強化プラスチックの複雑構造への適用
⑤	複合材製燃料タンク	・ガスバリア性に優れた液体水素タンク ・爆発の危険性のない複合材製液体酸素タンク
6	商業宇宙輸送の法制化	・航空および宇宙の垣根を超えた安全性設計と審査基準の構築

＊②③⑤は，世界に誇れる技術として開発と基礎研究に注力