B10

JAXAにおけるロケット・衛星の非デブリ化研究について

JAXA debris mitigation research activities for satellite and Launch Vehicle upper stages

大坊俊彰, 飯森祥子, 清水隆三, 藤本圭一郎, 斉藤靖博, 東出真澄,
足立寛和, 松本純(JAXA)
Toshiaki Daibo, Sachiko Iimori, Ryuzo Shimizu, Keiichiro Fujimoto, Yasuhiro Saitoh,
Masumi Higashide, Hirokazu Adachi and Jun Matsumoto (JAXA)

2016年にJAXAのデブリ対策活動を再編してデブリ低減(非デブリ化)に関する研究を立ち上げ、今年度より最大のデブリとなるロケット上段を含めた活動とした。リエントリ中の環境評価技術の向上やそれに向けたデータ取得、各種ミッションに対する軌道上寿命低減などの実現可能性検討などを実施している。また、経済性とデブリ低減の活動を両立するための方策としても上段再使用についても検討を始め、必要となる技術などの抽出を行い今後の長期シナリオを設定している。現時点までの検討と今後の展望について報告する。

Since 2016, JAXA has started debris mitigation research activities for satellite and Launch Vehicle upper stages by including upper stage mitigation issues. These activities include re-entry analysis model enhancement, data acquisitions of upper stage re-entry, and debris orbital life shortening methodology studies. And we consider the debris mitigation strategies to be compatible with launch vehicle competitiveness.
For that we've started studying upper stage recovery system and necessary technologies to make future research and development plan.

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- Debris mitigation has been one of the most important topics of JAXA's satellite and launch vehicles upper stages. So, we had excuted many kinds of researches on that issue.

デブリ低減は重要問題としてとらえられてきており、従来より各衛星・ロケットプロジェクトの中で個別の課題について検討がなされてきた

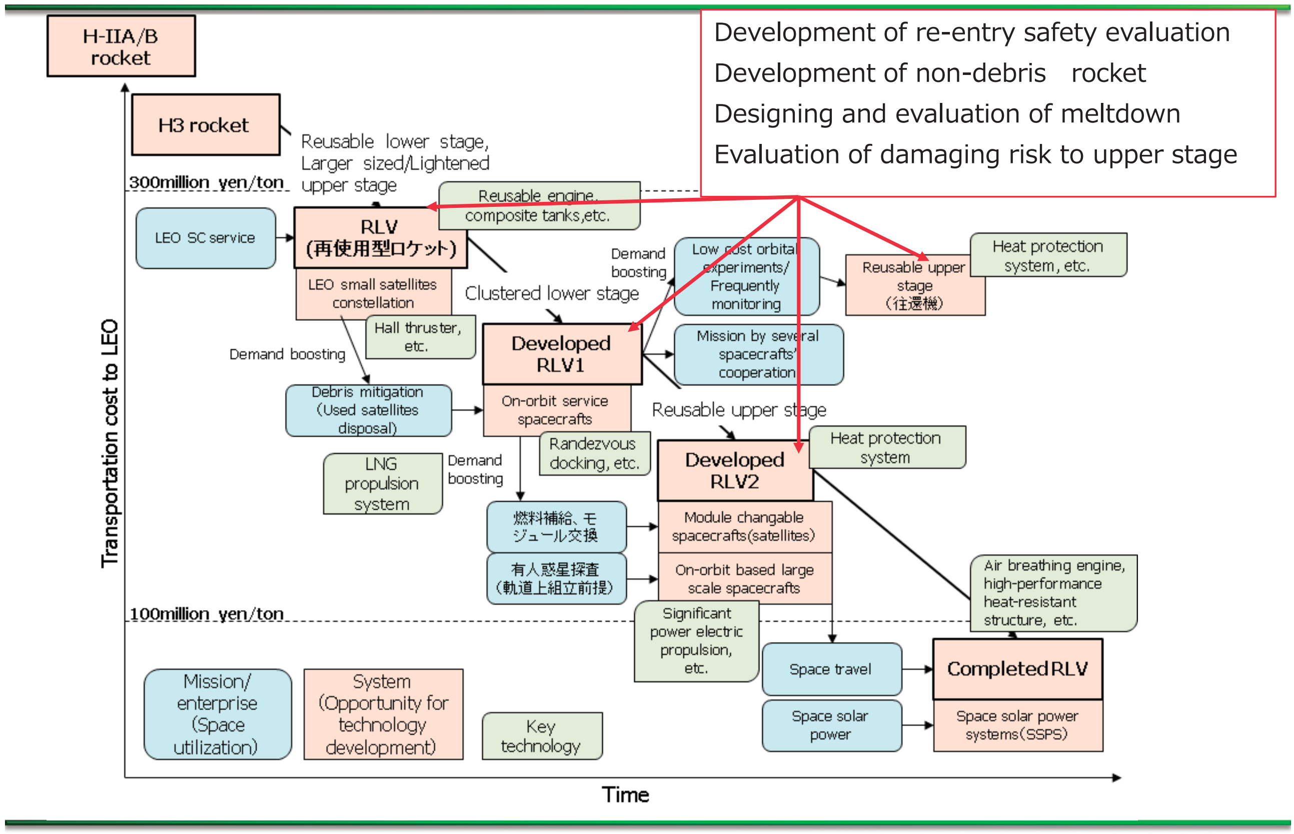
- In 2016, Debris mitigation activities were recognized as major research topics, and those kinds of research activities were integrated.

2016年に非デブリ化研究として、再編され研究開発部門の活動として定義された

- In 2018, this research activities include Launch Vehicle upper stage debris mitigation issue to contribute prohibit new debris generation by launches.

2018年より最大のデブリの一つとしてロケット上段に対する活動も含め、今後のデブリ低減に向けた研究活動を実施していくこととした

Future Milestones of Japanese Rocket



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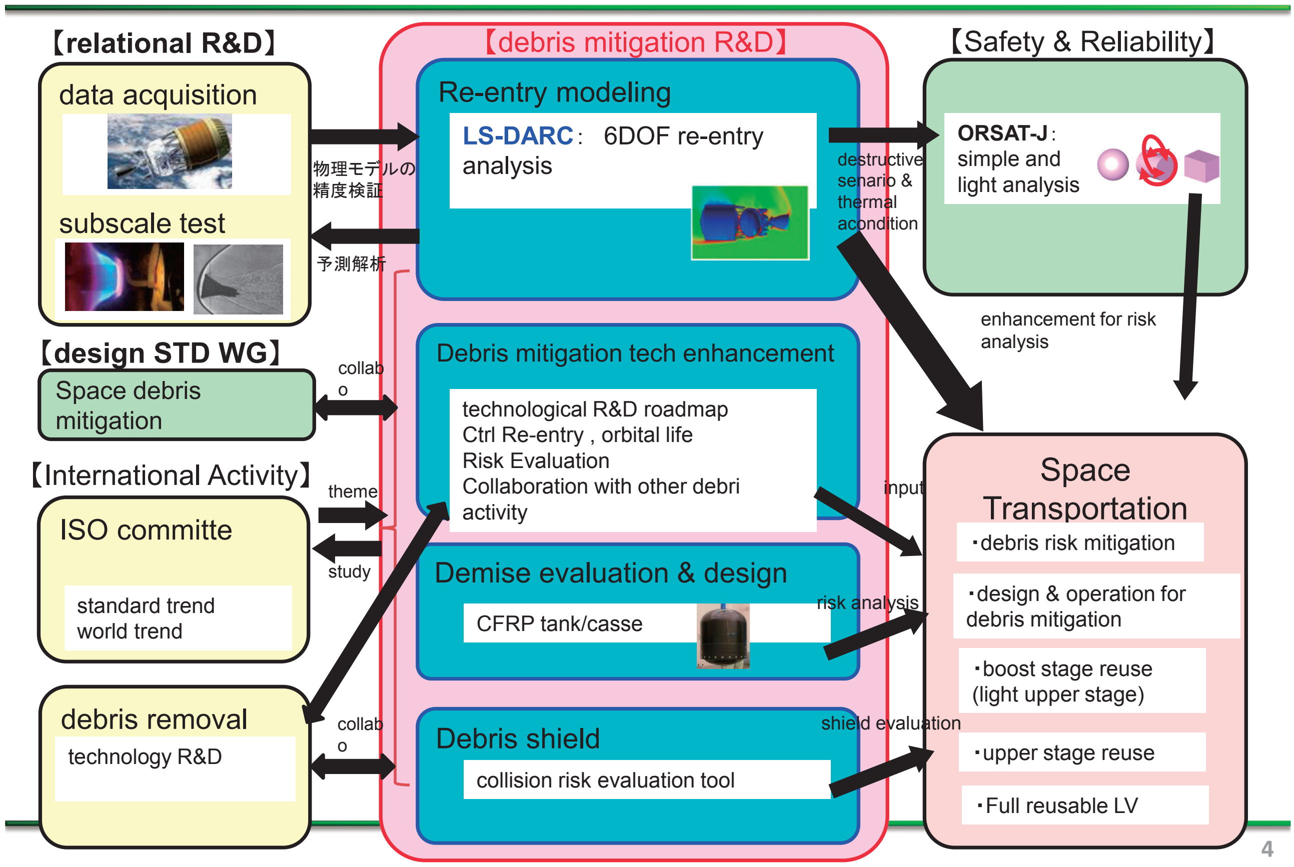
Debris mitigation Research activities



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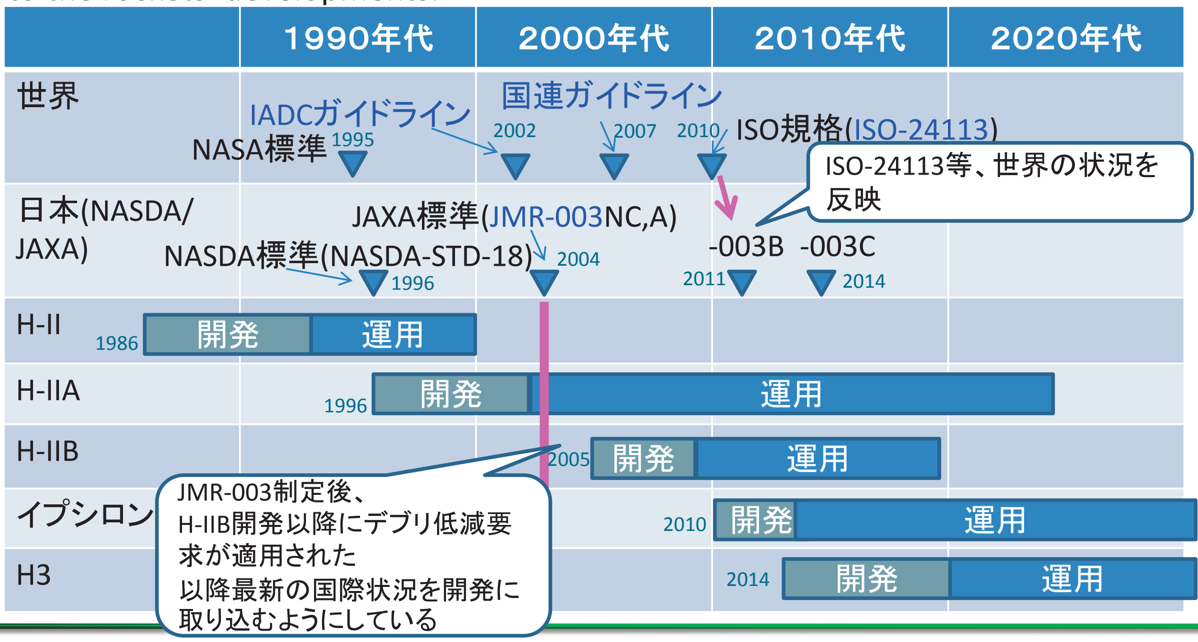
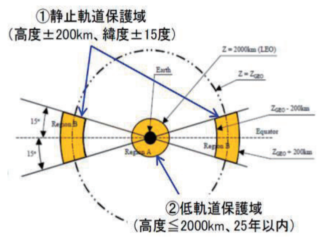
Japan's rocket development and debris mitigation

- 日本(JAXA)は、世界に先駆けてデブリ低減要求制定に取り組んでおり、JAXA標準の制定を受けて、それ以降の基幹ロケット開発に順次適用されてきた。
  Jaxa has been working on debris mitigation standards and has been applying them to the rockets' developments.



Debris Mitigation Considered in H3 rocket

- H3ロケット開発においては、ISO等の状況を反映したJAXA標準(JMR-003C**「スペースデブリ発生防止基準」**)を開発当初から適用している。
  Debris mitigation standard in JAXA is also applicable to H3 rocket development.
- H3における「デブリ発生防止活動方針」として以下4項目を揚げている。
  ① 運用終了後、軌道上での破砕を防止する。
  Prevention of on-orbit break-ups after mission completion.
  ② 事前に軌道上の有人宇宙システムとの衝突が起こらないよう解析(COLA解析)し、打上げ可否の判断を実施する。
  Analyse (by COLA analysis) not to make collision to manned space systems beforehand to decide launch GO/NO GO.
  ③ 運用終了後の第2段機体は、原則として低軌道及び静止軌道の保護軌道域との干渉を回避する。
  Minimize the interference of the upper stage in LEO and GEO protected area after mission completion.
  ④ 上記③に必要な能力余裕が無い場合は、25年以内に自然落下させる。
  If ③ is not applicable, natural decay should be planned within 25 years.



Required Actions for Debris Mitigation in ISO,Japan space activity law and STD, etc.

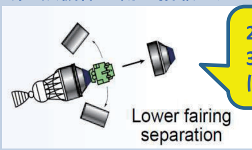
Classification	Outline of Requirements	Actions taken in JAXA
Operational Debris 運用中放出品	Not to release parts that could possibly stay in earth orbit.	Designed not to release parts intendedly.
	No solid motors' residue released in GEO. Also need consideration in LEO.	Current study issue
	Not to release combustion product (over 1mm)	Current study issue
On-orbit breakups 軌道上破砕	No intended break-ups.	No intended break-ups.
	Incidental break-up incidence rate should be no more than 10^{-3}	This may affect accomplishment of mission. Thus, handling by designing, increasing degree of confidence for preventing break-up by defect.
	Remove residual stored energy after mission completion or prevent explosure and break-ups by designing.（残留推進薬放出、圧力容器の破砕防止設計など）	・Designed to discharge residual propellants or not to destruct when it couldn't completely discharge. ・Explosure prevention design of VRV(逃気弁) etc. for propellant tanks and batteries ・Ensure autogenous ignition margin and inactivate command destruct soon after orbit injection
Collision 衝突	Set launch time that prevents collision with manned space systems for a defined certain period of time after liftoff.	Set launch window which does not make collision to manned space systems

Required Actions for Debris Mitigation in ISO,Japan space activity law and STD, etc.

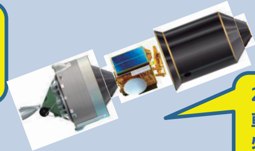
Classification		Outline of Requirements	Actions taken in JAXA
After mission completion 定常運用終了後の処置	GEO mission 静止衛星打上げミッション	GTO altitude of apogee to be lower 200km or more than GEO. Altitude of perigee to be set to satisfy lifetime within 25 years . （Conditional success probability >0.9） （Otherwise set altitude of perigee higher than LEO protected zone.）	Inject satellite between LEO protected zone and GEO protected zone or natural decay within 25 years by decreasing altitude of perigee （For future, controlled re-entry when having capability allowance in review）
		Deorbit from GEO as below after mission completion. Spot altitude (地点高度) to be set to satisfy lifetime within 25 years. ・Altitude equivalent to 235km+(1000・Cr・A/m) ・Eccentricity(離心率)<0.003 ・No interference for 100years	Reorbit in between LEO protected zone and GEO protected zone (In review)
	LEO mission 低軌道ミッション	Lifetime within 25 years （Conditional success probability >0.9） （Otherwise move altitude higher than LEO protected zone but not reccomended.）	Controlled re-entry or natural decay within 25 years by decreasing altitude of perigee
	Ground safety when re-entry 再突入時地上安全	Not to exceed the desired value of expectancy of casuality of re-entry object.	When natural decay, it is hard to satisfy the desired value as for other large sized rockets, but continuously working on reducing expectancy of casuality. For controlled re-entry, plan the falling area to satisfy the requirement.

Required Actions for Debris Mitigation in ISO,Japan space activity law and STD, etc.

Classification	Outline of Requirements for ISO 24113 revision planned in Sep.2019	Actions considering in JAXA
Number of objects allowed to inject in orbit 軌道投入物体数の制限明確化	Number of objects allowed to inject in orbit at successful launch will be as follows: Single satellite launch : Up to 1 Several satellite launch: Up to 2 正常な打上げで軌道に投入する物体数が以下に限定される。 ・シングル衛星打上げ　1個まで （ロケット第2段機体のみ） ・複数衛星打上げ：　2個まで （ロケット第2段機体＋衛星搭載アダプタ）	Need consideration (because of the configuration of dual satellite launch fairing, etc.) (The launch operation configuration in H-2A will be prohibited and needs changes, like the configuration in SYLDA, ARIANE5.) デュアル衛星打上げ用フェアリング等の形態上、考慮が必要。（現行H-IIAのデュアルフェアリングのような形態は不可となり、Ariane 5のSYLDAのような形態とする必要がある）
Success probability of disposal 廃棄成功確率の規制強化	【NOW】 After mission completion to end of disposal's success probability =0.9 「運用終了～廃棄終了の成功確率0.9」 【Planned revision】 Beginning of mission to end of disposal's success probability =0.9 「運用開始～廃棄終了の成功確率0.9」	Quantitative evaluation needs to be relyed on calculation of degree of confidence, but since mission time of rocket is short and degree of confidence after mission completion is high, it is expected to have little affection. 定量的な評価は信頼度計算に頼らざるを得ないが、ロケットはミッション時間が短く、ミッション（運用）終了時点の信頼度が高いため大きな影響はない見通し。



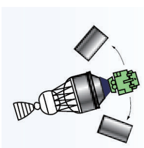
【H-IIAデュアルフェアリング下部フェアリング分離形態】



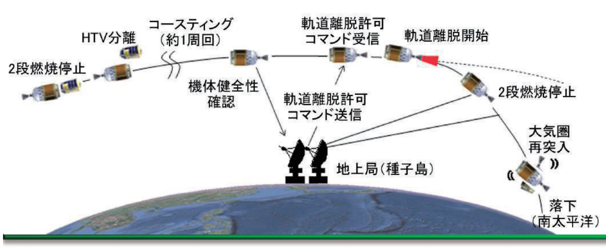
【Ariane 5デュアルフェアリング下部フェアリング分離形態】

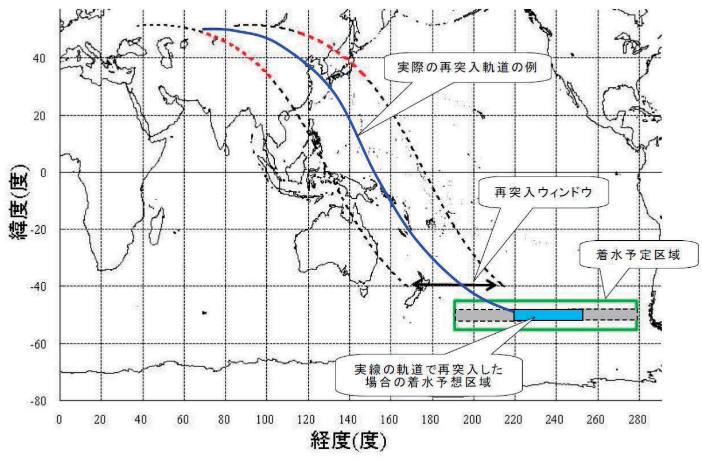
Challenges in Debris Mitigation

- 軌道寿命の低減　Lifetime reduction
- 制御再突入の実現　Controlled re-entry
- 落下時リスク最小化　Re-entry impact risks' minimization
- 制御再突入と競争力の両立　To ensure launcher's competitiveness with Debris mitigation operation

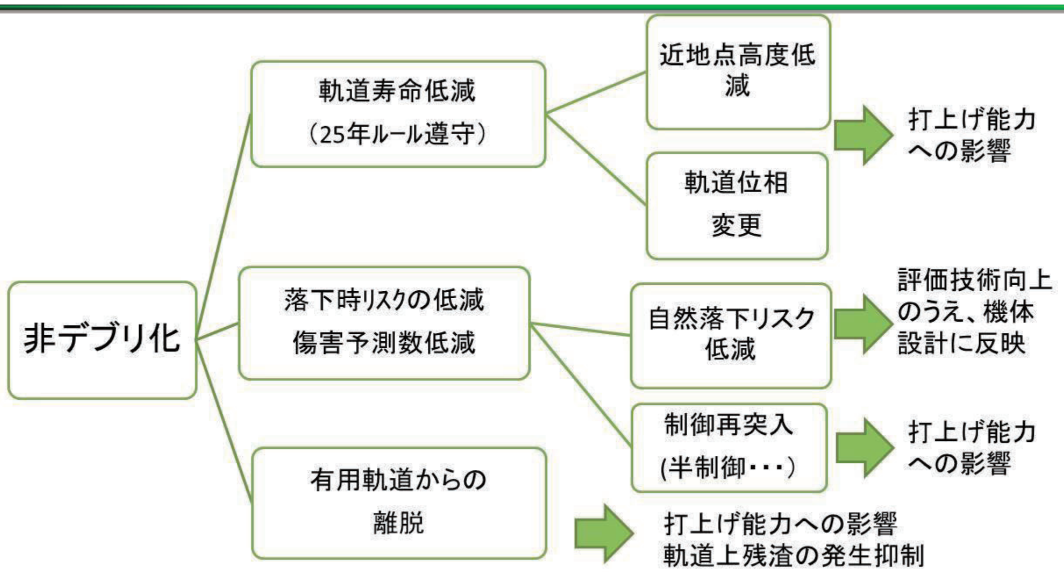


軌道寿命と自然落下時のリスク低減





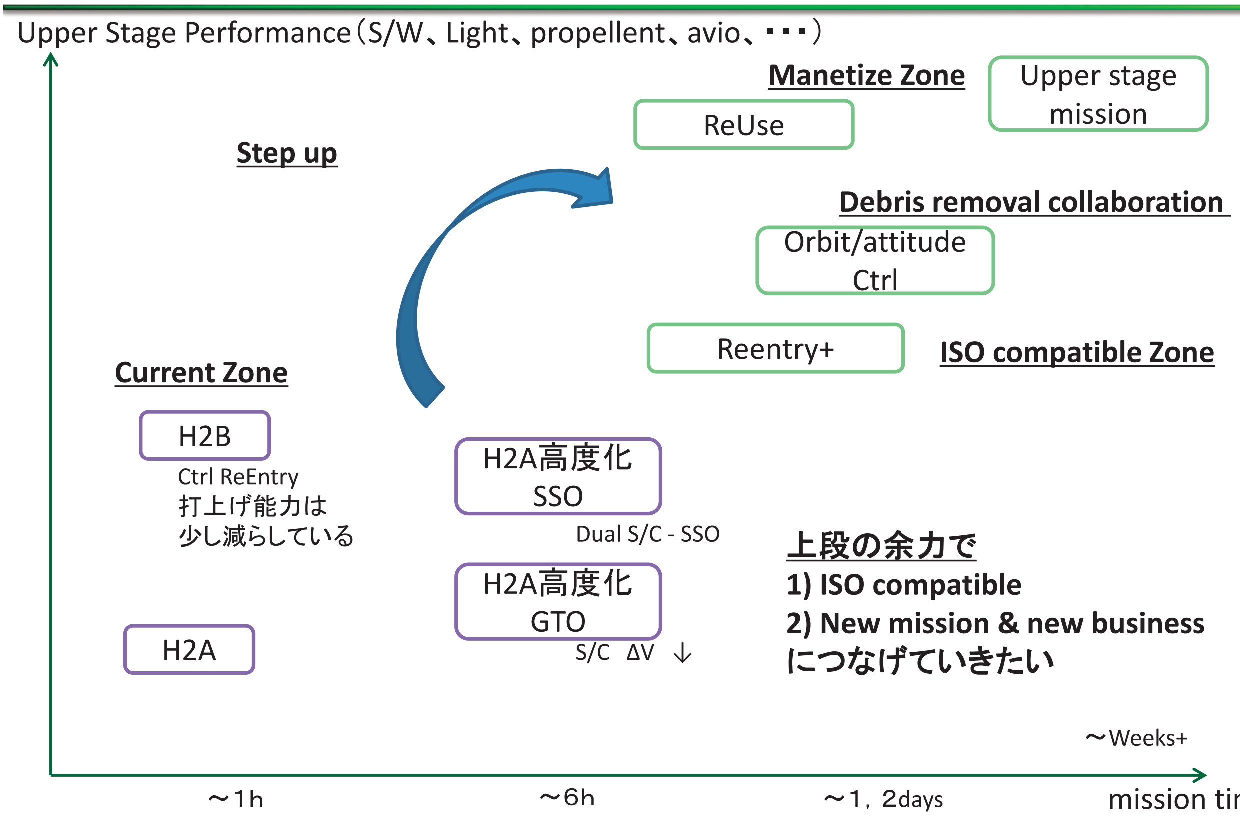
図－１　ＨＴＶ３の着水予定区域



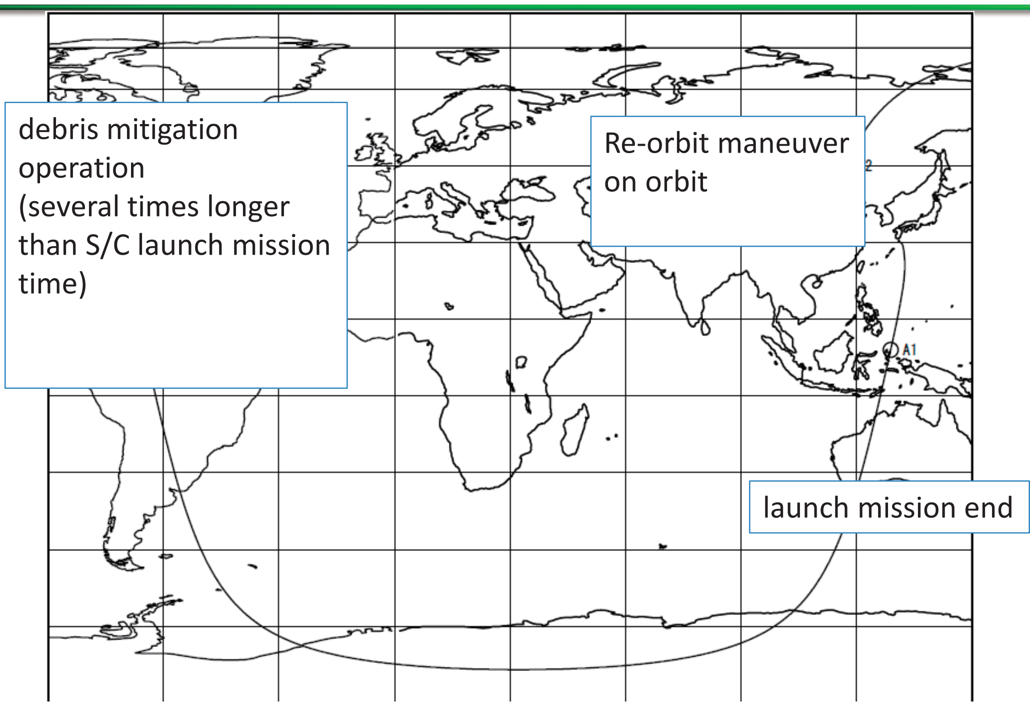
<u>打上げ能力への影響を低減しつつ、落下におけるﾓﾃﾞﾙ化の忠実度を上げ、ﾘｽｸ評価を適正化する。また、将来的に経済性との両立のためにもﾛｹｯﾄ能力余裕の確保が有効</u>

- Debris mitigation vs Launch capability loss & operation time
- Surplus upper stage capability can be used for debris mitigation.
- Surplus capabiilty will be also used for S/C or other service.

Improvements Required for Upper Stage Debris Mitigation



SSO debris mitigation example

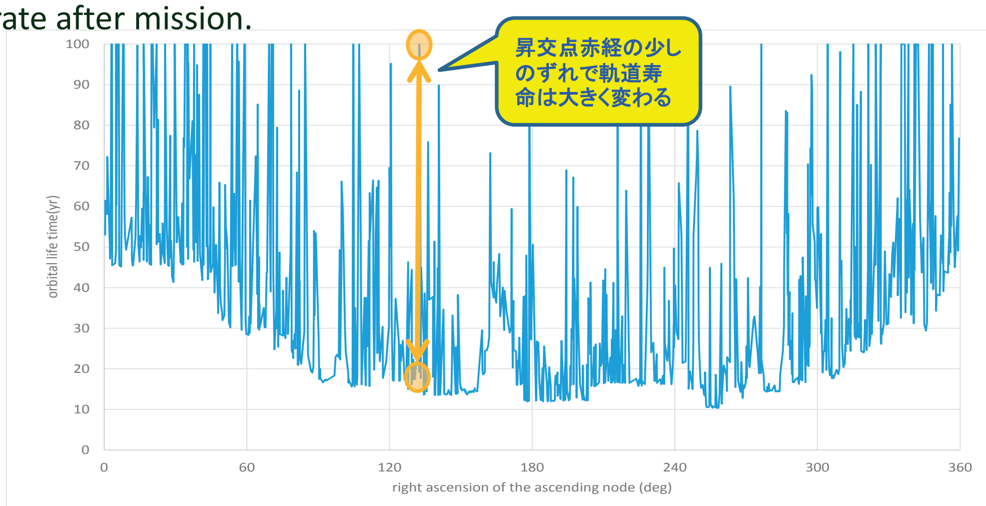


- SSO Re-Orbit Case must consider Gound site. That results in long mission life.

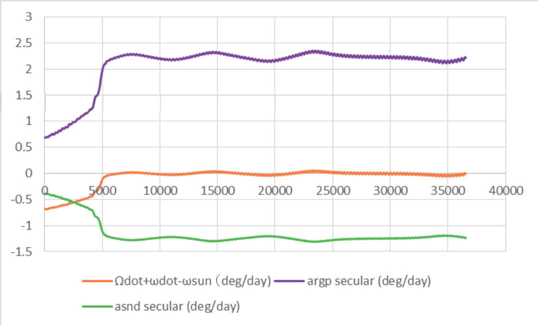
Reduction of Orbit Lifetime

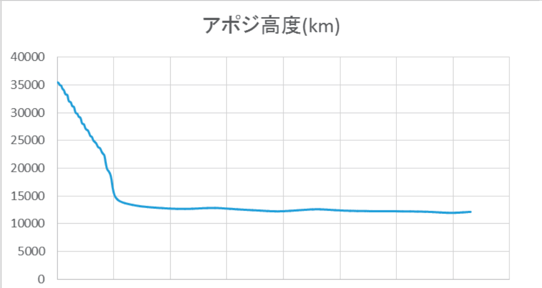
- GTO軌道では25年以下とする昇交点赤経の区画は限られており、昇交点赤経が少し違うだけで軌道寿命が大きく異なる。
- これらを考慮した運用マヌーバを検討している。

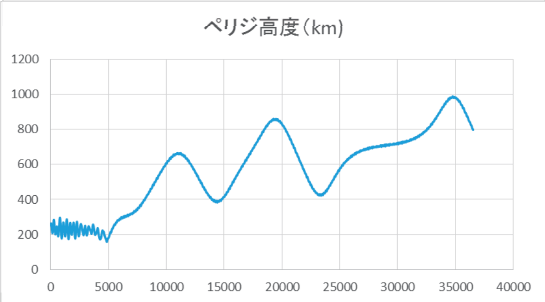
In GTO missions, the results of lifetime differs a lot , even by a small variation of the right ascension of the ascening node. So we must consider this phenomena to operate after mission.



昇交点赤経 vs Lifetime（35500 km × 250 km）







- Relative position between orbit and sun is almost static at certain long axis diameter value.
- At that time perigee altitude will be up in case axis is bad direction.

GTOミッション終了後のロケット上段は遠地点高度徐々に下がるが、ある軌道長半径となった際に軌道面と太陽の相対位置が安定化する。

この際に軌道に対して太陽がどの位置にあるかで近地点高度が上昇・下降の運命が分かれ軌道寿命に大きく影響している

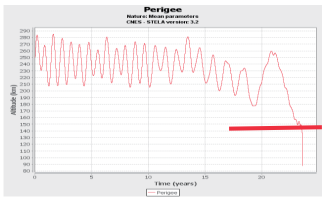
Outline of Risk Assessment of Natural Decay

- 下記評価の流れ

Definitive orbit injection

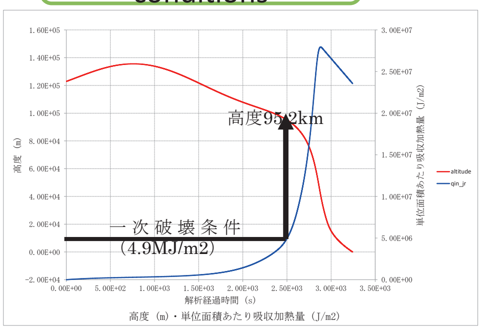
ﾛｹｯﾄ上段、下部FRG、ｱﾀﾞﾌﾟﾀなど
軌道上に残る物体の6要素などを
飛行解析で確定
6 factors that will remain on orbit is decided.

Decision of orbit lifetime and falling orbit



ﾘｴﾝﾄﾘ落下高度までの
軌道寿命解析を実施
Lifetime analysis until the re-entry fall altitude

Analyze fragmentate conditions



Debris meltage analysis evaluation

破壊条件後は破片化し、
破片毎に破壊後の溶融解析
を実施
残存物のﾘｽｸ評価を行う。

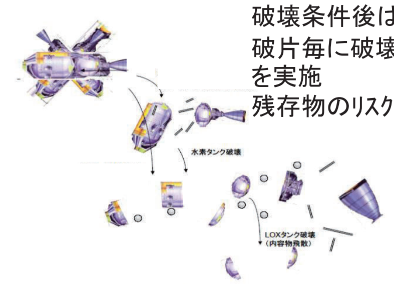
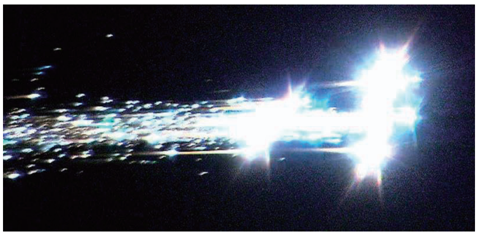


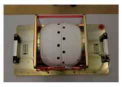
図4-0 第2段機体破壊シナリオ

Each debris' meltdown analysis conducted after destruction and evaluate risk of residue

Actions Needed for Natural Decay Risk Assessments

- Changing analysis conditions may make an improvement in the precision of analysis.
- There are few observed and measured samples for what is happening when natural decay.

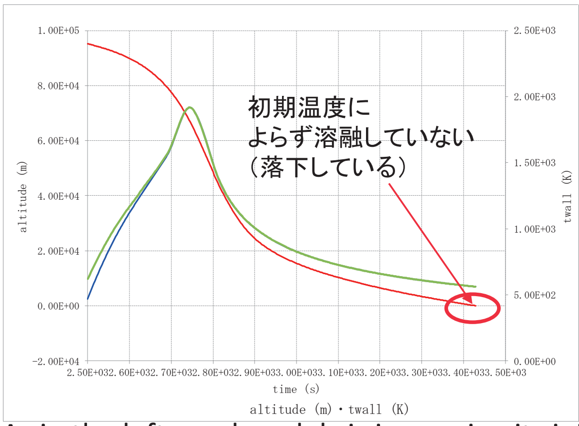


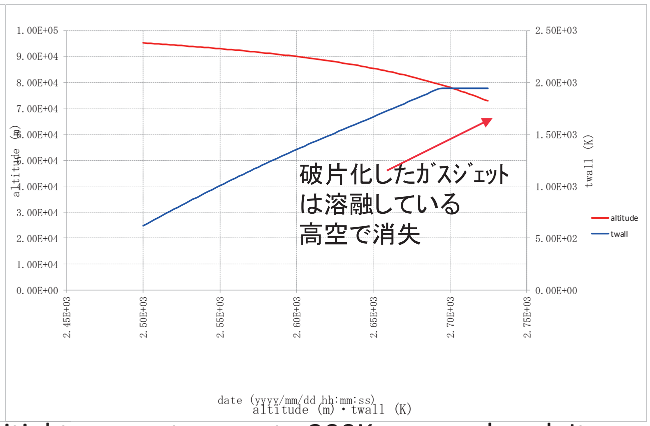
	BUC	REBR	i-Ball
			
開発者	Ruag	Aerospace Corporation	IHI
サイズ	Φ300mm	φ300mm	Φ400mm
質量	?	8.6kg	42kg
取得データ	加速度、磁力、回転数、温度、画像 伝送時間は弾道落下中のみ	温度･加速度･角速度 伝送時間は弾道落下中のみ	温度･加速度･角速度･画像 海面上からもﾃﾞｰﾀ送信可能
実績	1回のﾌﾗｲﾄ （画像送出は失敗）	4回のﾌﾗｲﾄ （失敗1回）	2回のﾌﾗｲﾄ
評価	ﾃﾞｰﾀ送信時間が短く、取得ﾃﾞｰﾀが少ない ATVが計画終了のため今後の計画は不明	ﾃﾞｰﾀ送信時間が短く、取得ﾃﾞｰﾀが少ない 今後無線ｾﾝｻ搭載し機体各部のﾃﾞｰﾀ取得も検討	画像取得可能だば、温度計測点数が少ない

- Each country has been updating their evaluation methods by measuring data when operating re-entry using on-board sensors,etc.
- Destruction conditions are the biggest factors that affect the risk. It is required to establish evaluation method that includes physical events and not just mathmatical evaluation.

Factors that Affect Falling Risks on Ground

- No hazards will occur if the rocket doesn’t fall on the ground. The results of parametr ic study on conditions of rocket when falling considering destruction is shown below.



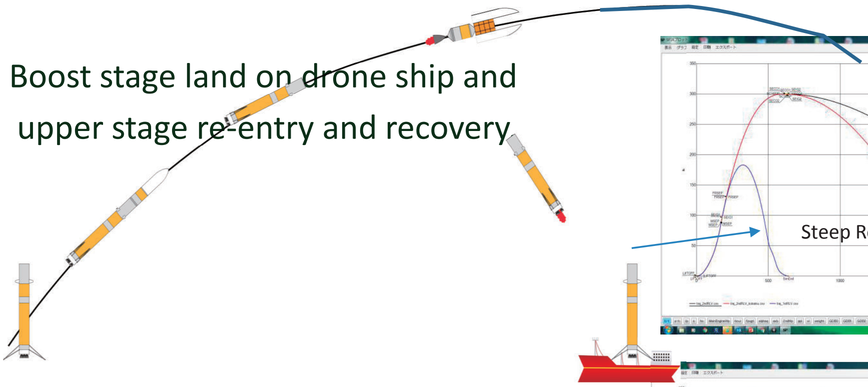


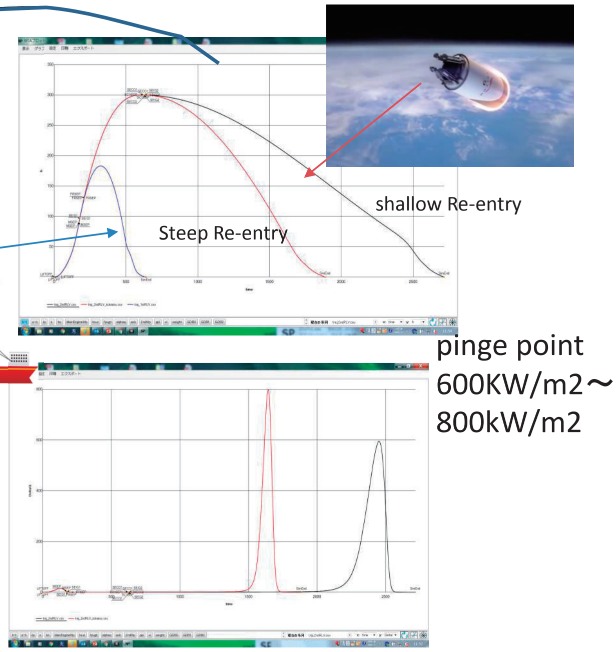
As in the left graph, a debris increasing its initial temperature up to 200K was analyzed. It does not meltdown.
In condition of the debris additionally fragmentating, it will meltdown thus would have no risks on the ground.
In future studies, we will conduct analysis and measurements that will specify the details of destruction behavior since the rocket rearward will be more heated when falling, having engine on the upper stream.

Recovery system study for upper stage

To ensure launcher’s competitiveness with Debris mitigation is current topics. One example upper stage recovery system is currently studied.

経済性とデブリ対応の一例として上段回収システムの検討なども実施している。





Recover and Reuse upper stage is expected so that debris mitigation and economical compettitiveness can be consistent with.

Sizing study shows difficulties in recovery system

項目	単位	1段	2段	3段
m0	kg	284,729	22,068	1,500
mf	kg	106,649	6,308	1,500
構造効率	-	0.866	0.850	0.800
有効推進薬	kg	224,000	16,000	0
PC	%	79.5%	98.5%	
消費推進薬	kg	178,080	15,760	0
残留推進薬	kg	45,920	240	0
構造質量	kg	35,661	4,568	0
投棄物	kg	3,000		
ペイロード	kg			1500.0
Isp(vac)	s	425.0	448.0	
推力(vac)	tonf	450.0	16.0	
燃焼時間	s	168.2	441.3	
増速	m/s	4092.8	5501.8	
出口面積	m2	2.47		
エンジン数	基	3	1	1
推力(sea)	tonf	373.6	16.0	0.0

帰還用

項目	単位	1段	2danR
m0	kg	86,389	4,808
mf	kg	40,928	4,574
構造効率	-	0.866	0.850
有効推進薬	kg	45,920	240
PC	%	99.0%	97.5%
消費推進薬	kg	45,461	234
残留推進薬	kg	459	6
構造質量	kg	35,661	4,568
投棄物	kg		
ペイロード	kg		
Isp(vac)	s	425.0	448.0
推力(vac)	tonf	450.0	16.0
燃焼時間	s	42.9	6.6
増速	m/s	3113.6	219.2
出口面積	m2	2.47	
エンジン数	基	3	
推力(sea)	tonf	373.6	

- TPS will be 50% and more of re-entry vehicle weight。Recovery system weight must be considered. That results in losing launcher’s competitiveness.

TPSと回収系の質量を考慮すると打上げ能力は激減する。
→現状、何のためにやっているかわからない状態

- Launcher will lose 90% of satellite capability, in case current technology and restriction.

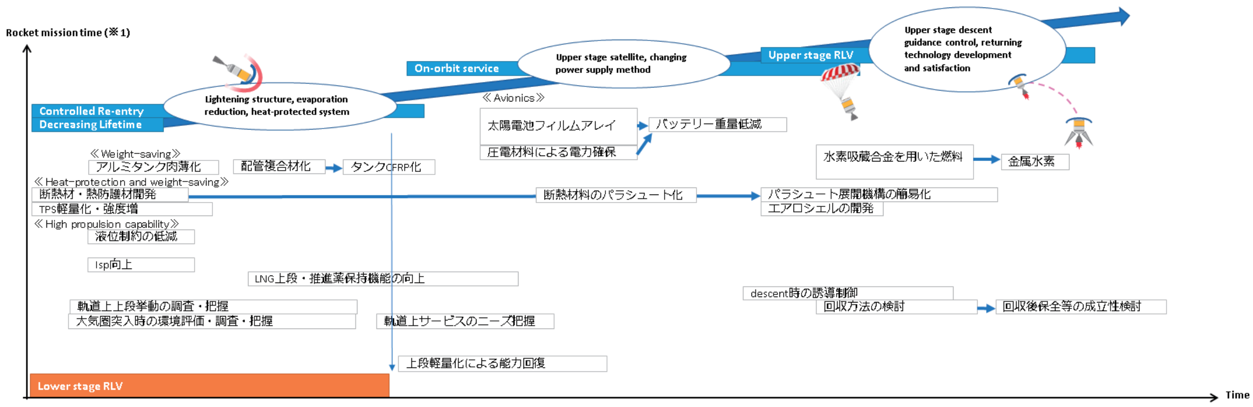
長期的な研究として、打上げ能力向上およびTPSなどの軽量化研究に向けた活動を実施している
（一部共同研究などを調整中）

Debris mitigation to be compatible with launcher's competitiveness

- 多方面・多分野にわたる技術の発展・向上を行い、非デブリ化につながる各要素技術を含めた長期シナリオを作成、実践していく

Debris mitigation and related esearch and development plan in various fields will be shown on technology roadmap for JAXA's space transportation.

It will include not only debris mitigation but launcher's competitiveness.



Summary

- Since this year, We have gained momentum in debris mitigation research by including launch vehicle upper stage to research activities.

今年度から非デブリ化研究にロケット上段を加えることで、より体系化した活動としている

- Debris orbital life, Controlled re-entry, and re-entry risk mitigation are studied.

デブリの軌道寿命低減、制御再突入成立性検討、再突入時リスク評価などについて種々の検討を実施している。

- To ensure launcher's competitiveness with Debris mitigation is current topics.

デブリ低減について、ロケットの競争力との両立が課題となっている。

- Future R&D roadmap will be issued to consider that debris mitigation actibities and launcher's competitiveness. That will include upper stage recovery system and debris removal collaboration.

ロケット上段再使用・デブリ除去との協調などに向けた長期的な研究活動についても検討し、長期シナリオとしてまとめ、継続的な活動を立案していく。