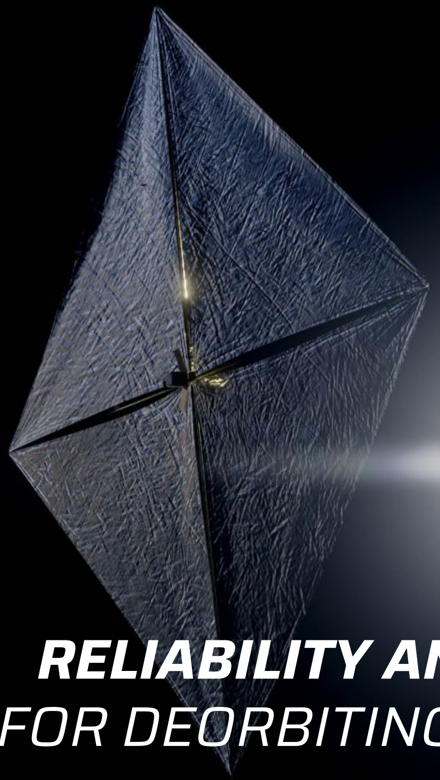
ASTRO**BRAKE**

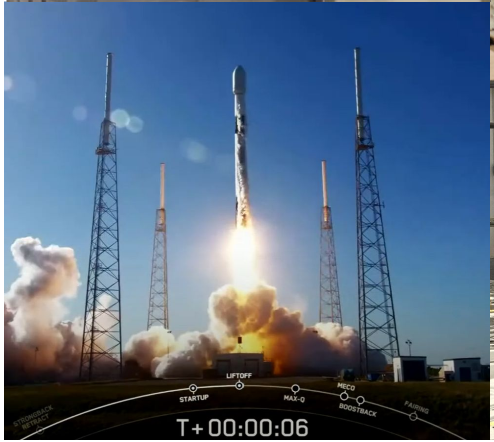


RELIABILITY AND SIMPLICITY
FOR DEORBITING SPACECRAFT

CLEANSPACE DAYS 2024
ESTEC - 09/10/2024

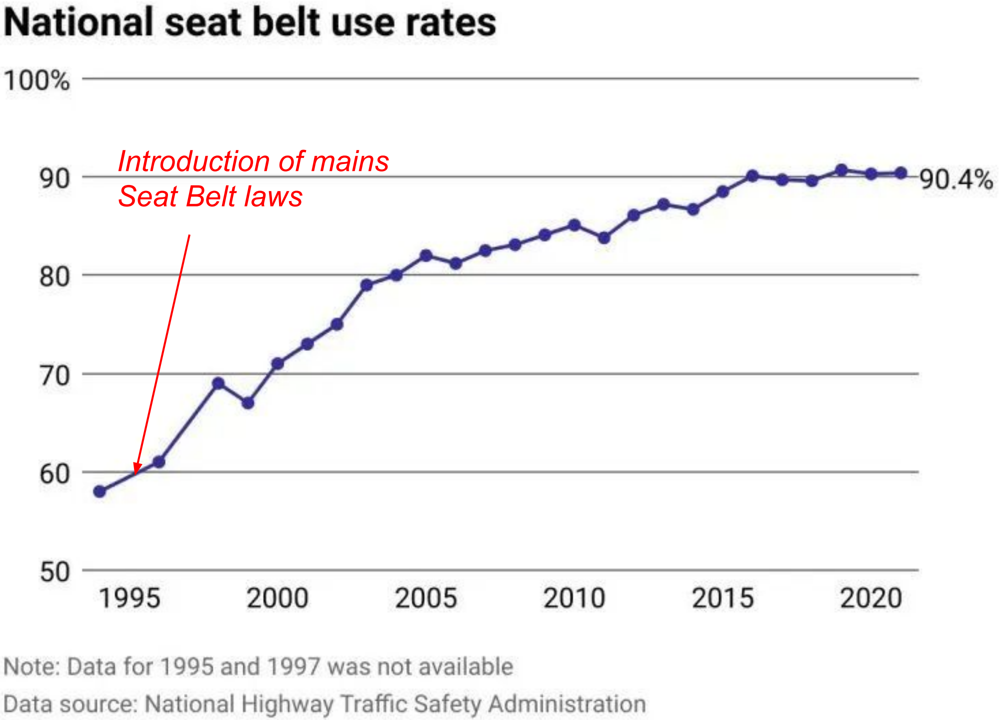
Information on this presentation is not contractual and might not reflect the final product

PRESENTATION
GAMA



THE SEAT BELT EXAMPLE (US)

1984, **65%** of Americans were **against mandatory seat belts** as well as **penalties for not wearing them** [1]



[1] "POLL FINDS INCREASE in PUBLIC'S CONCERN over SAFETY in CARS." *Nytimes.com*, The New York Times, 8 July 1984, www.nytimes.com/1984/07/08/us/poll-finds-increase-in-public-s-concern-over-safety-in-cars.html.

END-OF-LIFE REGULATIONS *AROUND THE WORLD*

ESSB-ST-U-007 Issue 1 part 5.4.1.1; ODMSP part 4.2; LOS Article 41-12

Probability of successful disposal
above 0,9 through to end of life


ESSB-ST-U-007 Issue 1 part 5.4.2.3; FCC 22-74A1

The orbit clearance time shall be
less than 5 years


In an effort to reduce the orbital debris footprint of the Rideshare Program, Payloads are expected to adhere to the FCC's rule requiring the disposal of spacecraft as soon as practicable but no later than 5 years after the mission ends.

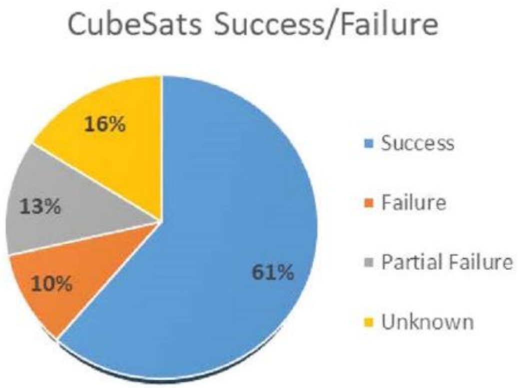
Figure 1: Excerpt from the Falcon 9's rideshare user guide

SATELLITE RELIABILITY CHALLENGES
MANY SATELLITES FAIL

Launch year	Launched	Failed	Censored
1990-2009	441	228	213
2010-2019	425	56	369

Figure 2: Categorization of small satellites based on launch year [2]

Only **60%** of Cubesats are successful



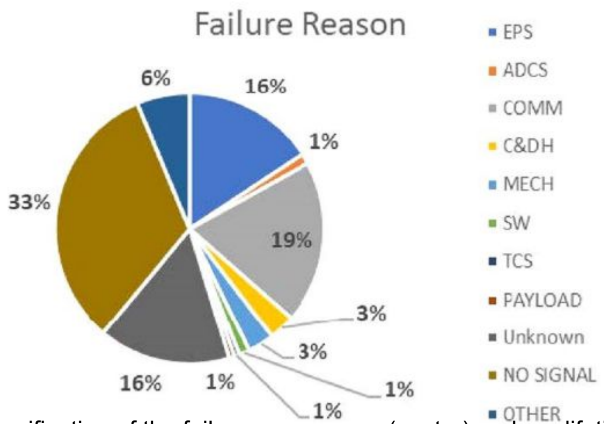


Figure 3: Rate of success/failure among the 672 analyzed CubeSats (left); classification of the failures per reason (center) and per lifetime (right) [3]

[2] A. Cervone et al., "The Path towards Increasing RAMS for Novel Complex Missions Based on CubeSat Technology," *CEAS Space Journal* 16, no. 2 (March 2024): 203–24, https://doi.org/10.1007/s12567-023-00517-9.
[3] Raja Pandi Perumal et al., "Small Satellite Reliability: A Decade in Review," n.d.

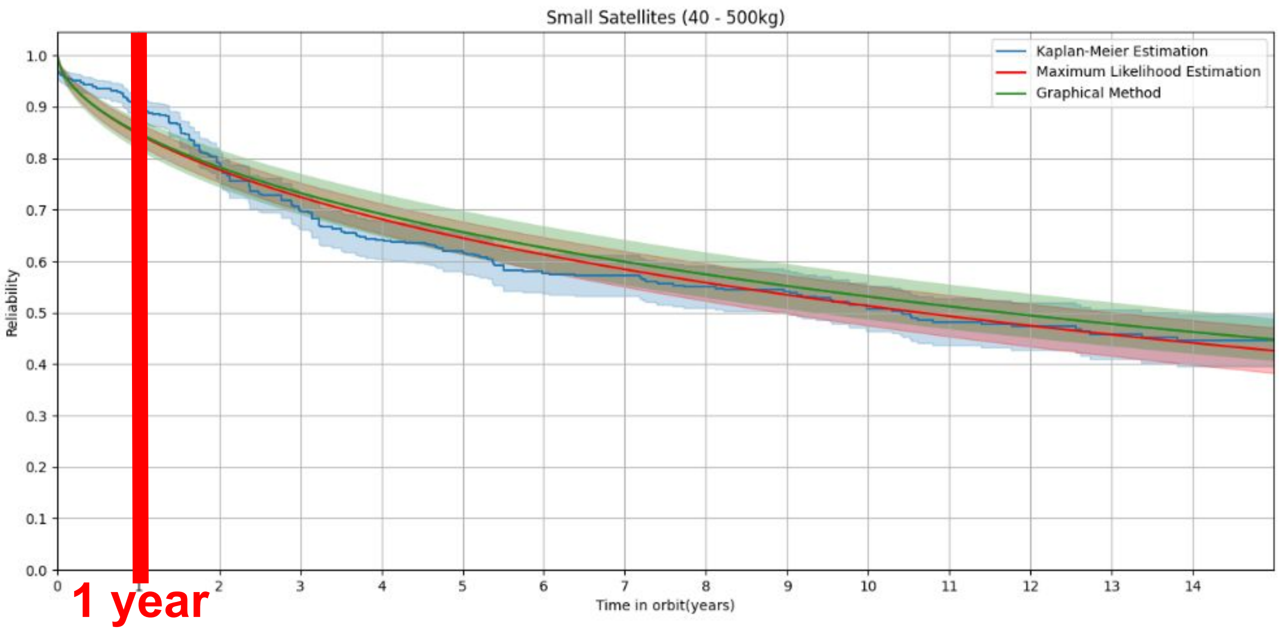


Figure 1: Collective reliability of small satellites launched between 1990-2020

To deorbit using propulsion, all the spacecraft subsystems **MUST** still be functional

[3] Raja Pandi Perumal et al., "Small Satellite Reliability: A Decade in Review," n.d.

COST-BENEFIT ***TRADE-OFF***

RELIABILITY REQUIREMENT

+ indirect costs for qualification of all subsystems required to deorbit
+ risk of not getting launch approval
+ risk of penalties

5-YEAR CLEARANCE REQUIREMENT

+ direct cost (more systems, more propellant, increased launch mass)
- Payload mass
+ indirect cost (increased complexity = more risks, more paperwork)

ASTROBRAKE

COST-BENEFIT ***TRADE-OFF***

But, with the right system, costs can be reduced

SELECTED BENEFIT-COST RESULTS for IMMEDIATE ELIMINATION of HDR at LAGUARDIA AIRPORT

Benefits and Costs by User Group	1995	2000
Dollar Benefits and Costs ($ Mil. per Year):		
Consumers:		
Fare Reductions	$160	$167
New Service	$78	$101
Increased Delay Cost	($149)	($226)
NET BENEFIT to CONSUMERS	$89	$42
Airlines:		
Loss of Fare Premium	($160)	($167)
Incremental Demand Impact	$104	$111
Increased Airline Delay Costs	($64)	($97)
NET BENEFIT (LOSS) to AIRLINES	($120)	($153)
Net Revenue to Airports:	$14	$24
TOTAL BENEFITS	$193	$236
TOTAL COSTS	($213)	($323)
NET DOLLAR BENEFIT OF ELIMINATING HDR	($17)	($87)

Source: "Report to Congress: A Study of the High Density Rule Study," May 1995, pp. 90-94.

Benefits and Costs by User Group	No deorbiting device	Other deorbiting device	Dragsail
Satellite Operators			
Purchase cost	[illegible]	[illegible]	[illegible]
Operation cost	[illegible]	[illegible]	[illegible]
Launch delay cost	[illegible]	[illegible]	[illegible]
Fines	[illegible]	[illegible]	[illegible]
Active deorbiting cost	[illegible]	[illegible]	[illegible]
Satellite Manufacturers			
Design costs	[illegible]	[illegible]	[illegible]
Qualification costs	[illegible]	[illegible]	[illegible]
Delivery delay cost	[illegible]	[illegible]	[illegible]
Launchers			
Launch authorization cost	[illegible]	[illegible]	[illegible]

THE COST OF **RELIABILITY**

90% reliability = P(FAILURE$_{\text{EPS + ADCS + PROPULSION}}$) < 10%

$$n = \frac{\ln(1 - Confidence\ Level)}{\ln(Reliability)}$$

Reliability	Number of test samples without failure (CL 95%)
80%	14
90%	29
95%	59
99%	299

x2

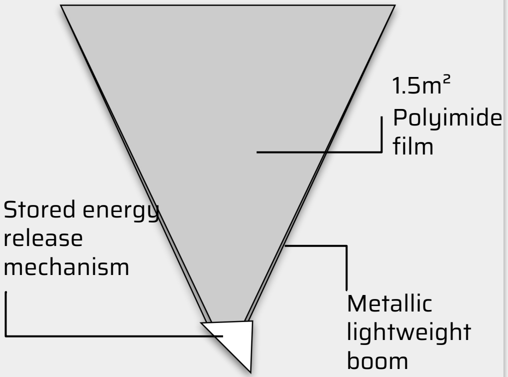
x2

x5

Assuming a binomial distribution

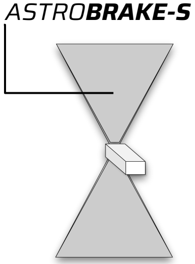
cost of **deorbiting device** < cost of **reliability** → **worth it**

THE PRODUCT LINE
ASTROBRAKE



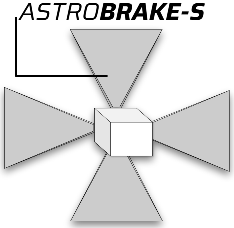
ASTROBRAKE-S
(deployed)

<30kg



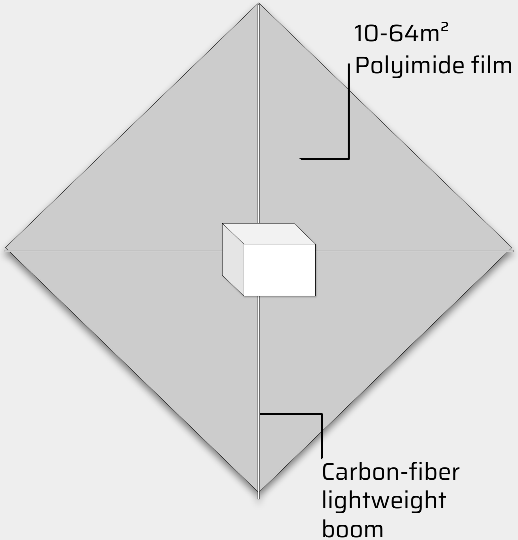
ASTROBRAKE-S2

30-50kg



ASTROBRAKE-S4

50-100kg

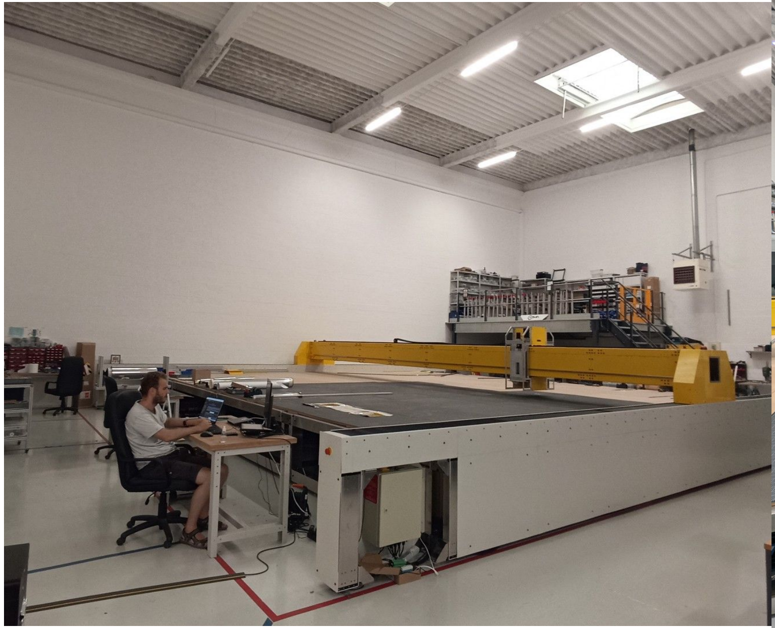


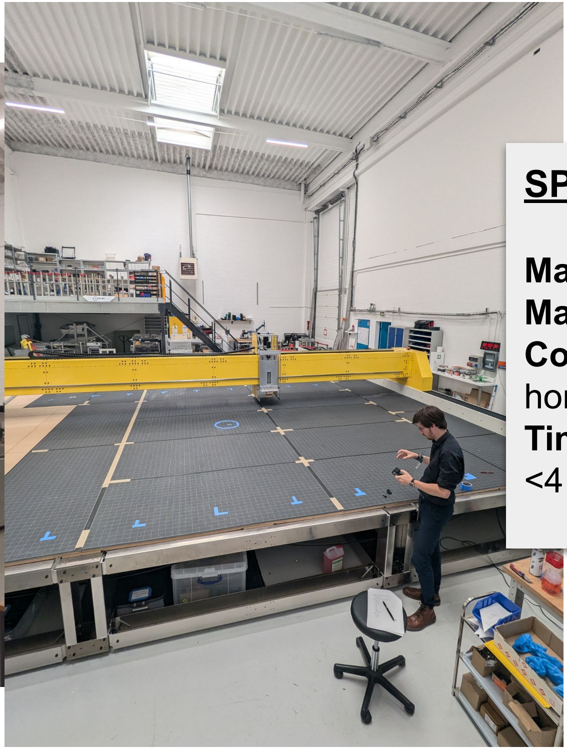
ASTROBRAKE-L
(deployed)

>100kg

MAIVOS (**M**achine d'**A**ssemblage et d'**I**ntégration de **VO**ile **S**olaire)

INDUSTRIALIZE AND STANDARDIZE



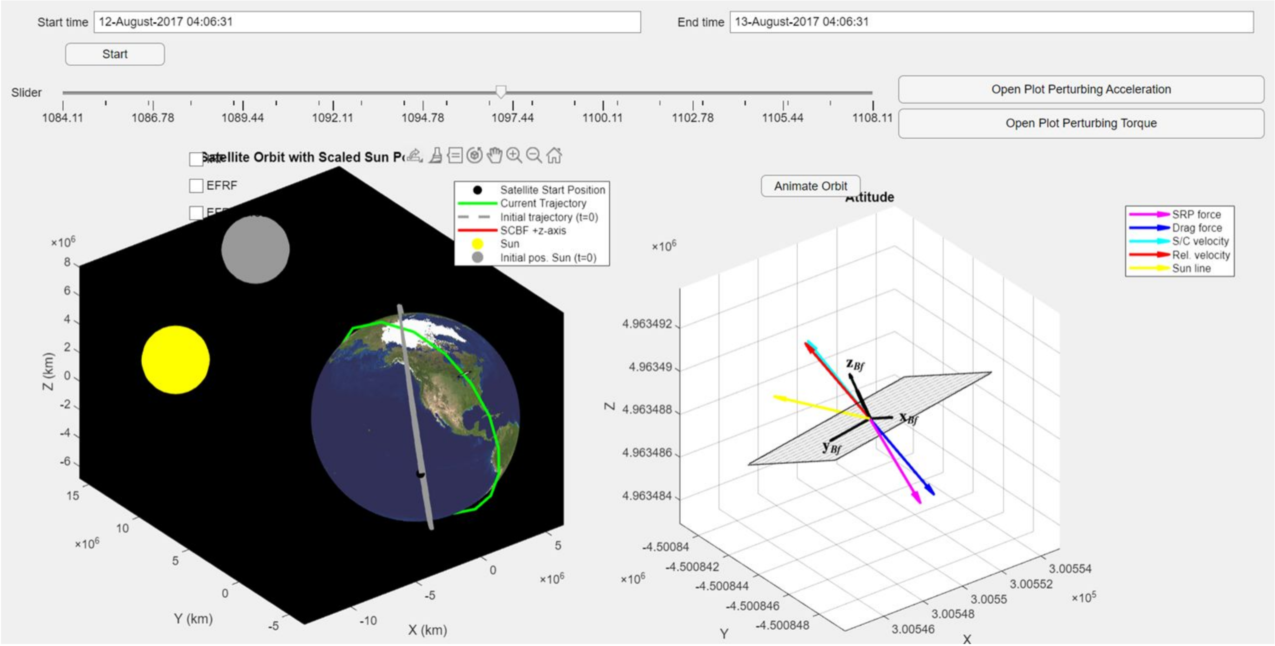


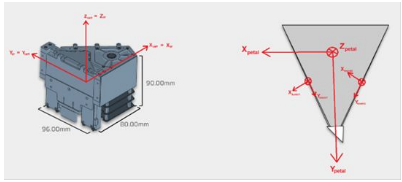
SPECIFICATIONS:

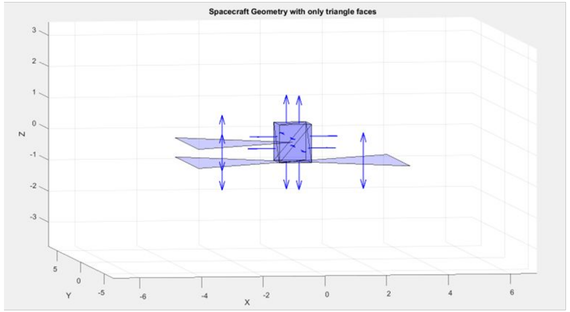
Max sail size: 64m²
Mass: 3.2T
Conception and assembly: homemade
Time to manufacture a 64m² sail: <4 days (with 2 operators)

SEXTANT **SOFTWARE**

- ➔ Simulate Orbital decay with high precision to compute optimal sail size
- ➔ Compute collision risks integrated throughout the deorbiting trajectory
- ➔ Generate report for regulations







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