

# Parametric Cost Estimation in the Preliminary Design Phase of Reusable Launch Vehicles

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Jascha Wilken, Sven Stappert, Martin Sippel  
German Aerospace Center (DLR), Institute of Space Systems



Knowledge for Tomorrow



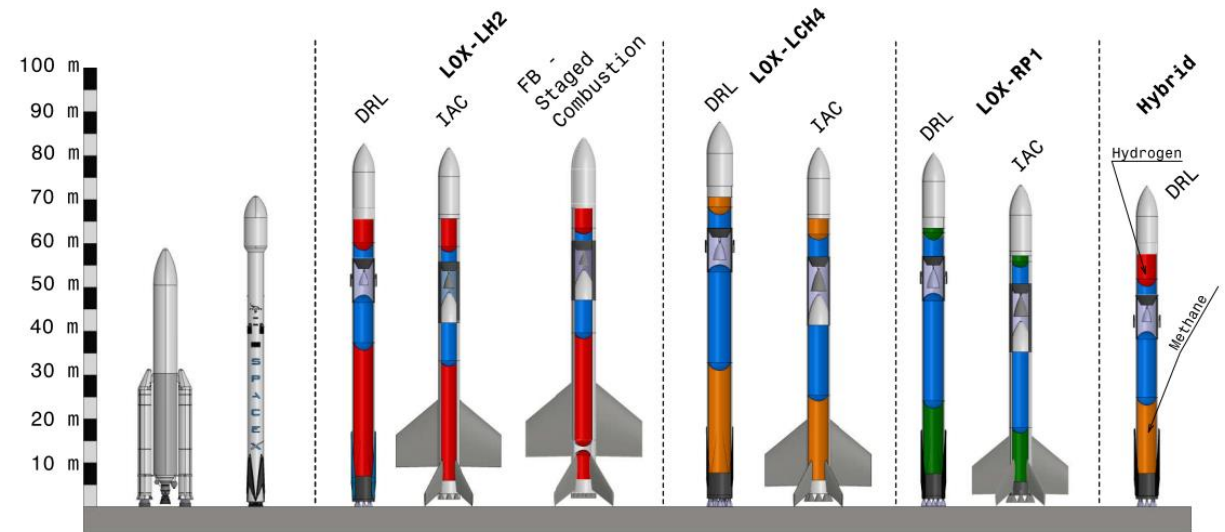
# Overview

- **Background & Motivation**
  - RLV Return Methods
- **Launcher Cost Estimation with TransCost**
  - Evaluation of ELV CERs
  - Winged RLV CERs
  - VTVL CERs
  - Statistical Approach
- **Recovery Cost Model**
  - Cost for recovery infrastructure/barges/landing pads
- **Conclusion/Outlook**



# RLV – Return Methods

- **Cost Modelling** important for evaluation of a **possible future European RLV**
- **RLV System Study** at DLR SART to determine **impact of return mode, propellants, staging and engine cycle** on the launcher design
- **VTVL** (Vertical Take-off, Vertical Landing) and **VTHL** (Vertical Take-off, Horizontal Landing) **launchers considered:**
  - Fly Back
  - In-Air Capturing
  - Return to Launch Site
  - Down-Range Landing
- **Goal: Assessment and comparison** of return methods on technical, operational and economical level → **which method offers the greatest possibility of cost reduction from a European perspective**



# Background

- **Motivation**

- Current developments (SpaceX) on the launcher market have shown that **reusable launch vehicles (RLVs) can reduce launch costs**
- What are the **impacts** of recovering and reusing booster stages on a technological, operational and **economical level** and can reusability be applied **to a European launcher?**

- **Problem:** Cost Estimation for RLVs is “unknown terrain” due to :

- Missing/Questionable data on cost of RLVs
- Difficult prediction of refurbishment costs and operational costs
- No active or historical RLVs in Europe → further infrastructural and production complications are difficult to assess

- **Question:** How can the total launch costs and all costs connected to reusability be modelled reliably?

- Approach: TransCost Model as baseline is extended with in-house cost estimation relationships.

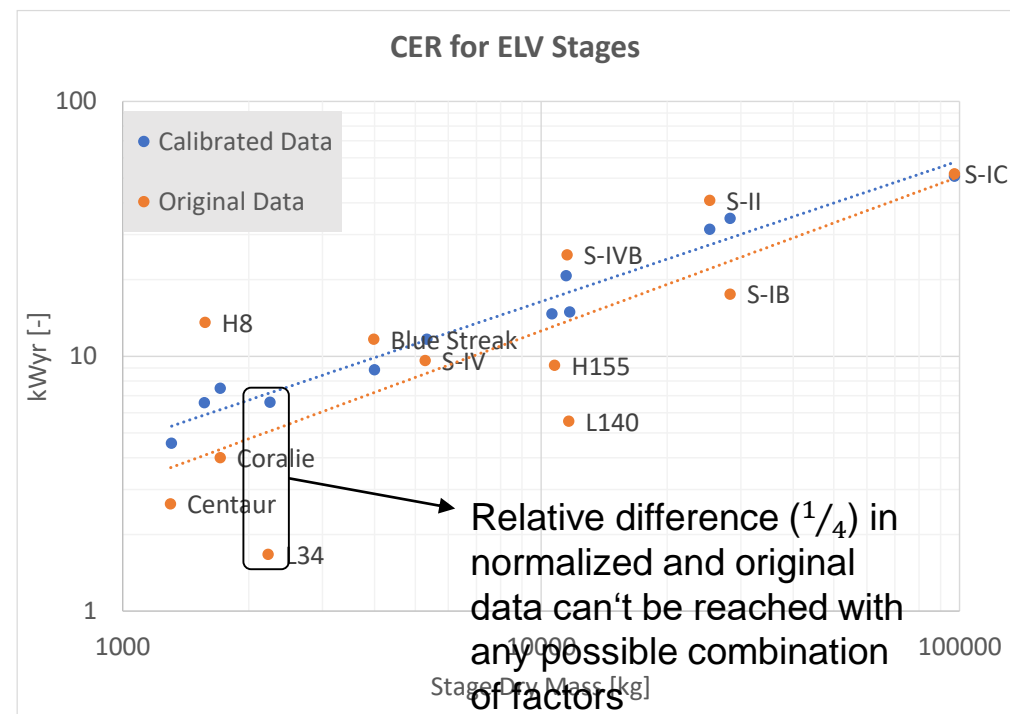


# Launcher Cost Estimation with TransCost - ELV

- TRANSCOST model uses top-to-bottom approach to model costs used for any costs
- TRANSCOST uses CER (Cost Estimation Relationship) based on historical launchers:

$$Cost = \sum_n f_n a \cdot M^x$$

- Factors  $a$  and  $x$  depend on the kind of system (ELV stage, booster, RLV...)
- Factors  $f_n$  are reflecting external circumstances and conditions such as team experience, technical difficulty, TRL of the technology, country efficiency...  
→ those factors are used to calibrate cost data and the choice is highly subjective
- **No explanation of calibration process or values for factors**

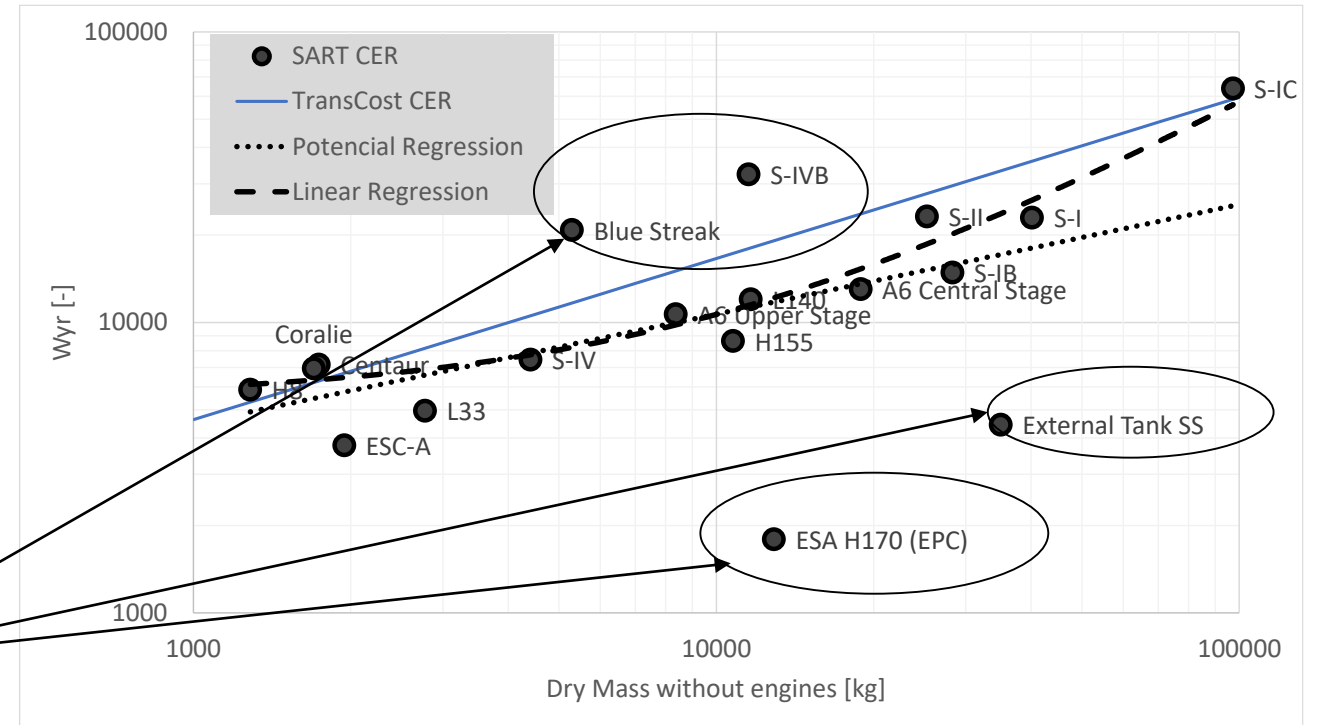


	<b>a</b>	<b>X</b>	<b>R<sup>2</sup></b>
Original	47.4	0.6059	0.6043
Calibrated	100.7	0.5528	<b>0.9625</b>



# Launcher Cost Estimation with TransCost - ELV

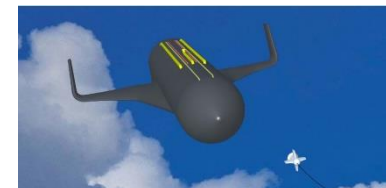
- Trying to reproduce calibration and regression leads to completely different values
- Selection of factors f1, f2, f3 and f8 has a huge influence on the final CER
- Available Database has uncertainties (different cost values from different sources)
- A few datapoints differ by a lot while most are quite close to the trend → **CER has to be improved and analysed further**
- **A statistical approach to cover the variance of the input data might be a better solution**



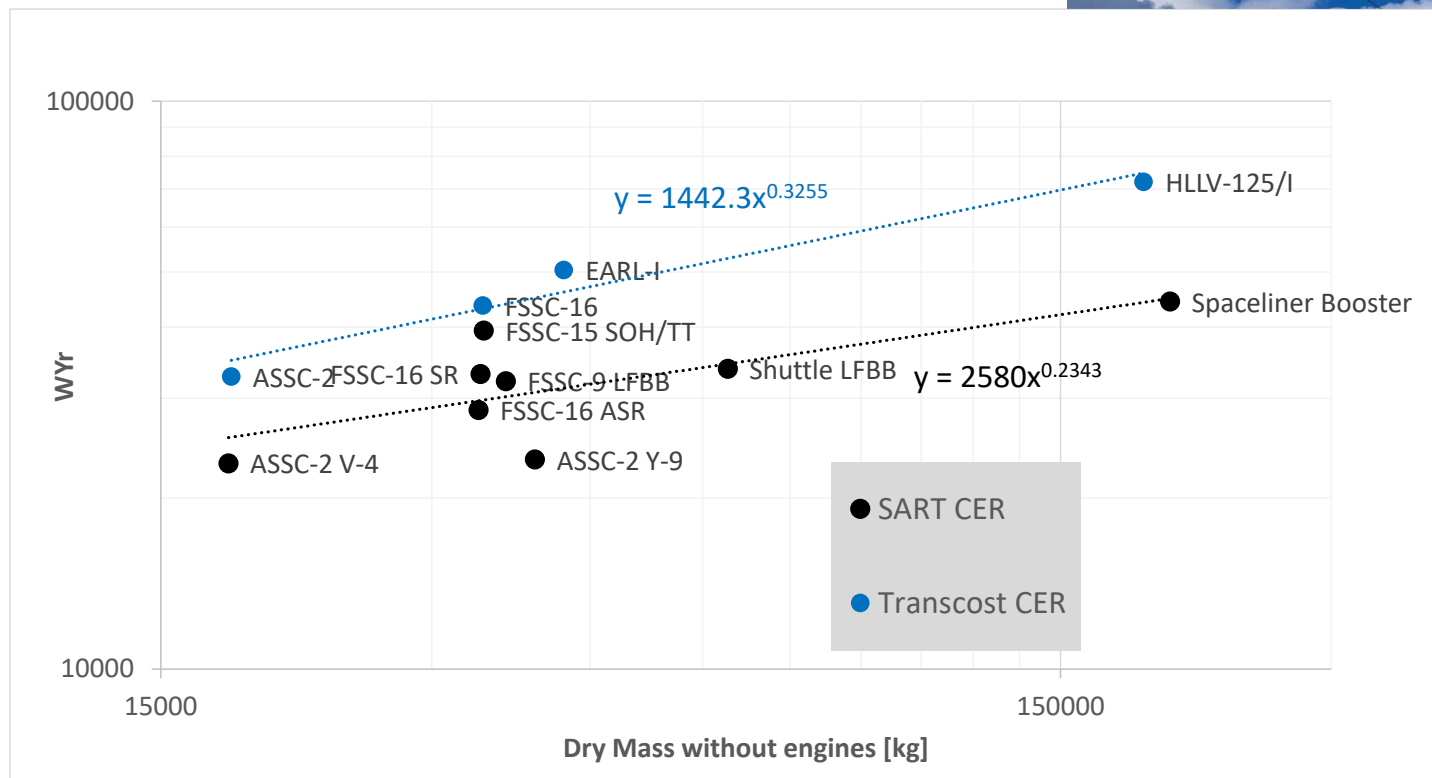
	$R^2$
TransCost	0.96
SART - Linear	0.68
SART - Potential	0.30



# Launcher Cost Estimation with TransCost – Winged RLV



- Establish Data points based on all possible available data
  - SpaceX Falcon 9 Cost Model
  - FESTIP VTHL Cost Calculations
  - TransCost RLV cost data
  
- Problem: Again the statistical variance on the cost data is large and there is no reliable data from a proven and operational concept → bad regression

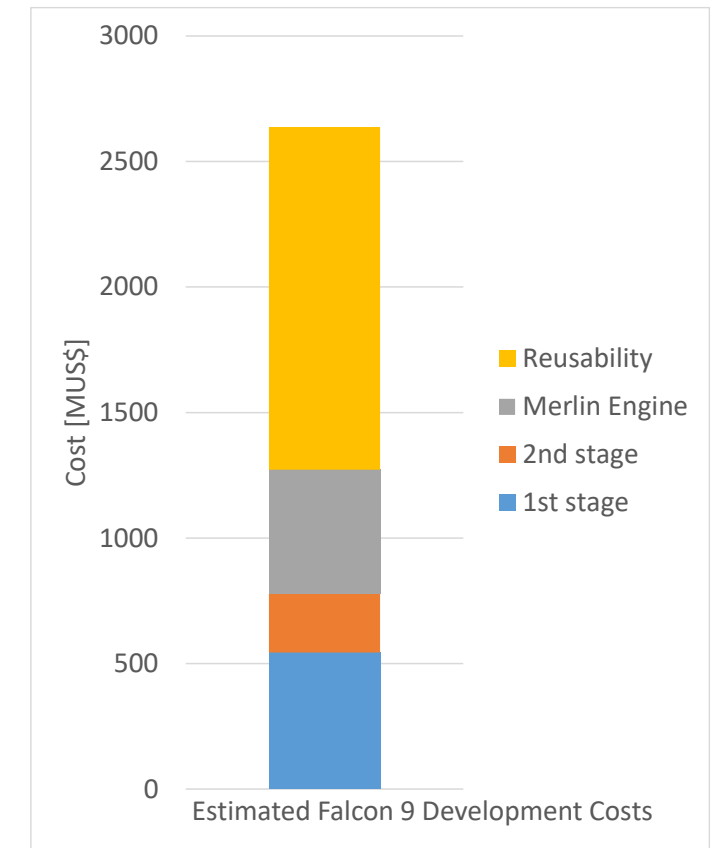


	R <sup>2</sup>
TransCost	0.95
SART	<b>0.51</b>



# Launcher Cost Estimation with TransCost – VTVL

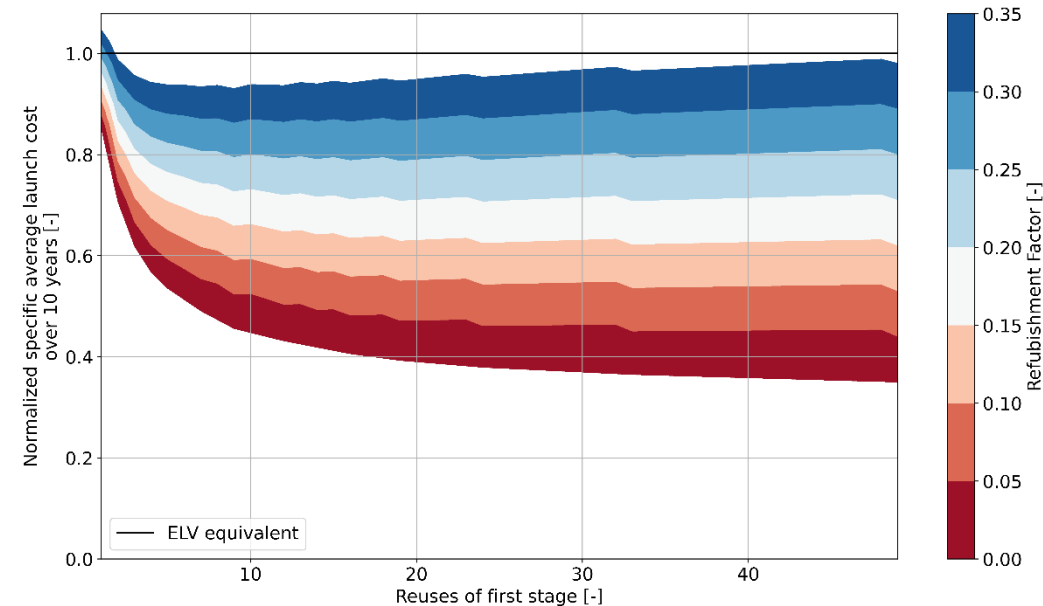
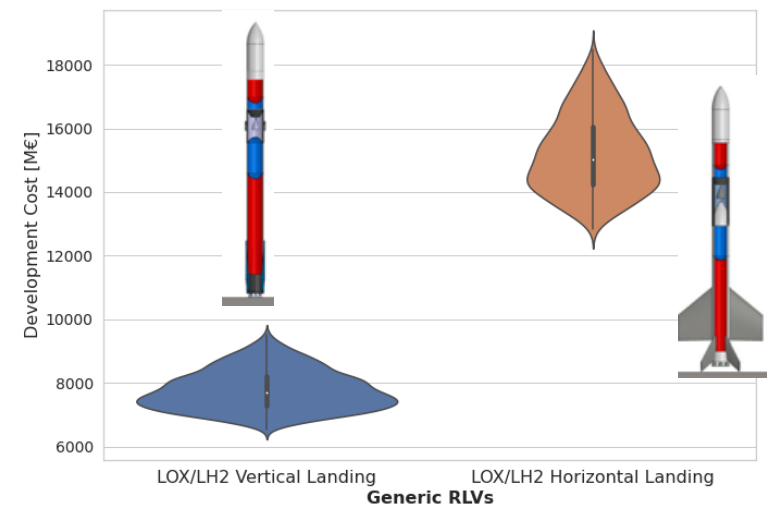
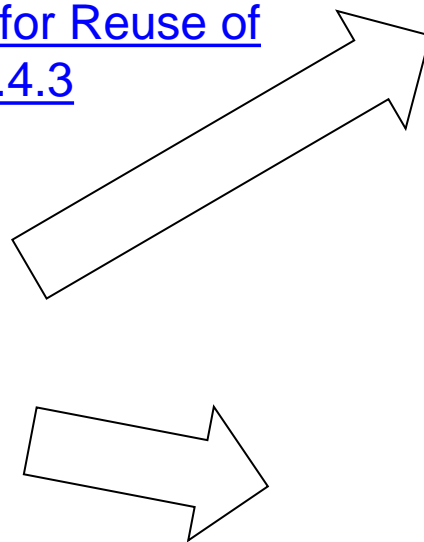
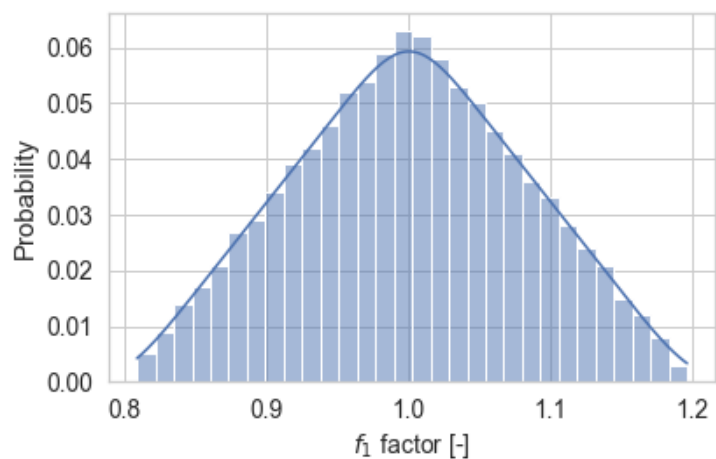
- VTVL CER from TransCost is only valid for SSTO vehicles or are based on experimental VTVL demonstrators (DC-X) → no application to Falcon 9 – like commercial vehicles or future European RLVs possible
- Using the TransCost Formula to calculate Falcon 9 development costs leads to too high development costs:
  - 25.9 billion € (2019) without commercial factors
  - 10 billion € (2019) with commercial factors
  - ~2.7 billion using preliminary model established by collecting all available cost information about SpaceX
  - Actual ~360 MUS\$ plus about a billion US\$ for adding reusability according to Elon Musk
- **Idea: Establish Data Point by SpaceX for “commercial” launchers and add reusability share to ELV CER**





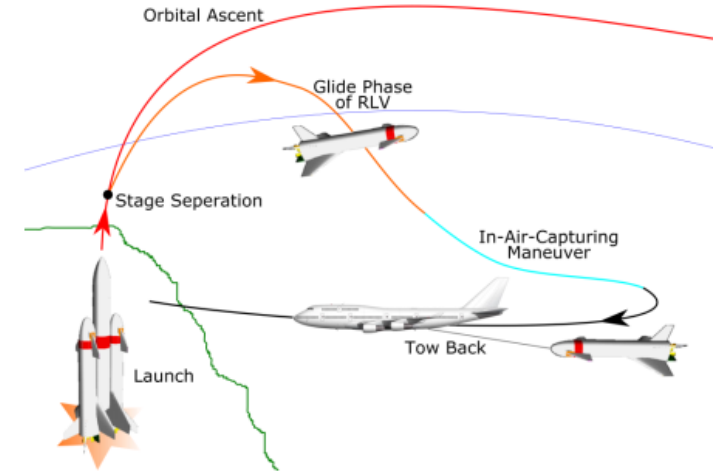
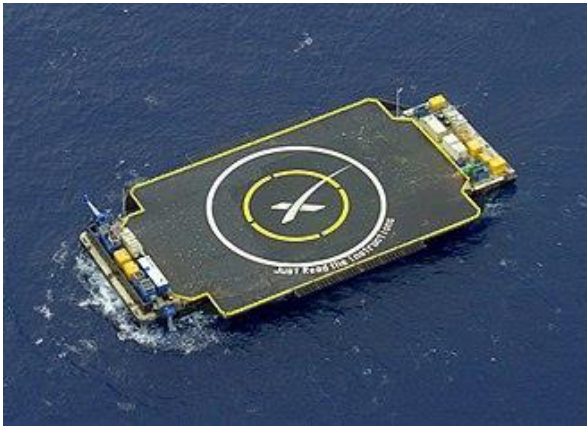
# RLV Launch Cost Estimation with TransCost – Statistical Approach

- Idea: Use of statistical approach to modelling launch costs for launchers, based on TransCost CER?
- Paper at IAC 2018 from MIT about this approach: [Vernacchia, M., Mathesius, K.: Strategies for Reuse of Launch Vehicle First Stage, IAC 2018, D2.4.3](#)



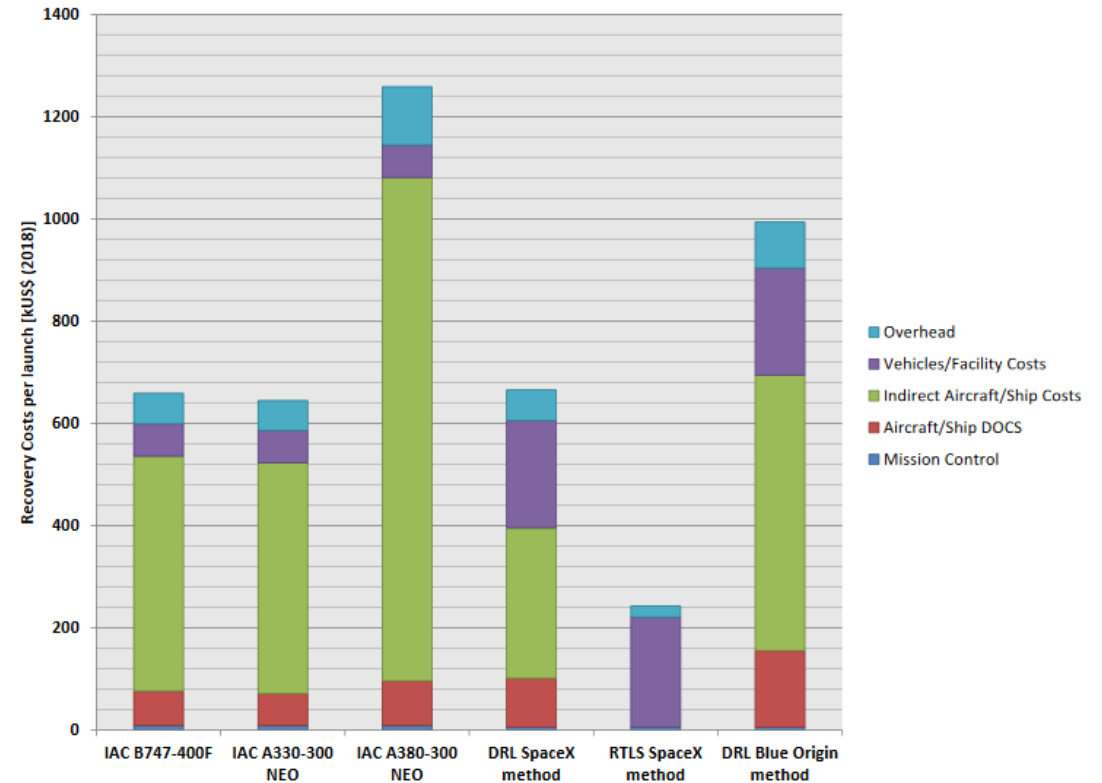
# Recovery Costs - Model

- Cost of In-Air-Capturing hardware, operations and personnel can be determined by a bottom-up approach: Estimation of subsystem and subtask costs based on viable cost models
- Aircraft operation cost models are broadly available and have been verified
- Determination of work effort and personnel based on historical data on aircraft, Space Shuttle ground operations, FESTIP reports, etc...
- Comparison with SpaceX method → barge costs and berthing prices are publicly available



# Recovery Costs

- **Recovery Cost model based on much bigger database compared to launcher cost model, since infrastructure and aircraft/boat cost models are based on much more data**
- **Launch Rate = 15 launches/ year**
- **Depreciation of acquisition costs over 15 year period**
- **Comparable Costs for In-Air-Capturing and Barge Recovery**
- **Low additional costs compared to total launch costs, mostly less than 1M\$ per launch**



## Conclusion & Outlook

- TransCost in its current version is not suitable for RLV cost estimation → too uncertain database and too high variance of input data
- TransCost CERs for expendable stages cannot be reproduced → high subjectivity of input factors vastly determines the final cost
- Potential RLV CERs could be established if the database on RLV would be big enough; for now, only preliminary CERs based on studies or very few operational vehicles are possible
- A statistical approach to modelling launch costs, taking uncertainties and variance in the database into account, could offer the potential to determine most probable costs with a certain confidence probability
- Future Work: Establish a model that is loosely based on TransCost CER while taking most recent launcher cost data and possibly statistical phenomena into account and combine with recovery cost model



**Thank you for your attention!**

