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Reusable Launch Space Systems

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Abstract
The paper focuses on reusable launch space systems. It aims to describe the current state of reusability in space systems and to analyze the launch cost of current Falcon carrier rockets.
The first chapter is dedicated to general information about reusable launch space systems. This includes definition of reusable and expendable launch systems or history of reusable launch systems. The second part is focused on the era after STS and new the concept of RLV. The following parts of this paper aim to analyze the launch price of current Falcon carrier rockets.

Keywords
Reusable launch system; Reusable launch vehicle; Spacecraft; Spaceplane; Launch vehicle; Spaceflight; Commercial spaceflight; Space industry

1. Introduction

A reusable launch system is a launch system intended to allow for recovery of part or all of its components for later reuse. An expendable launch system id designed to be used only once, and its components are not recovered.

The development of reusable launch space systems began in the first half of the twentieth century (between 1935 and 1945) by the Silbervogel project[1]. In the following of the post-war epoch cosmonautics was experiencing a rapid development that resulted in a piloted space flight and a landing on the Moon in 1969. Reusable launch systems became a major subject of development in the early 1970s. This epoch also gave rise to the largest project in the field of reusable space vehicles. It was the STS Space Shuttle program, which was the first reusable space vehicle to be operational. At present these space shuttles have already been retired from service for technical and economic reasons. Some economic and operational objectives of the project have not been fulfilled. It was intended to greatly reduce the cost of access to low Earth orbit, but it was criticized for failing to deliver on this goal.

2. Epoch after STS

At present it is possible to talk about the epoch after STS shuttles, which is characterized by the transition from state agencies to private projects. Especially in the case of the development of space transport systems and transport to Earth's orbit. Private projects often offer lower costs for the research and the space transportation than state-run organizations. State organizations however still play an irreplaceable role, notably in shifting the current astronautics boundaries.

2.1 SpaceX and Blue Origin reintroduced the concept of RLV

SpaceX since its foundation in 2002 aimed to develop a reusable carrier rocket system that would allow a reduction launch prices and kick-start the space economy. At present it

is the most important company in the field of re-use of space transport systems. SpaceX has developed a reusable rocket launching system to successfully re-use the first stage of Falcon 9 and Falcon Heavy. First successful recovery was in 2015 and first successful relaunch in March 2017.

In the future the significant competition for SpaceX in the field of reusable systems could represent Blue Origin company, which is also involved in the development of RLV.[2] In 2015 Blue Origin successfully landed with a sub-orbital New Shephard carrier rocket.

2.2 High development cost

he biggest issue for a reusable space system is high development costs and the low flight rate. This situation results in that other companies of the carrier rocket industry are still very conservative and cautious about reusability. An example of this may be United Launch Alliance (ULA), a joint venture of Boeing and Lockheed Martin, which operates Atlas V, Delta II and Delta IV carrier rockets. According to published information about future rocket Vulcan, ULA is considering only the reusability of rocket engines [11]. Re-usability in this form could be introduced by 2025 at the earliest. Airbus (Ariane) works similarly.

If we move from carrier rockets to space shuttles, there are several interesting projects currently running. For example the Boeing X-37 and Dream Chaser space shuttles.

3. Rocket reusability from an economic point of view

This chapter focuses on analyzing launch price of current Falcon 9 and Falcon HT rockets.

The Falcon 9 carrier rocket is a rocket used to carry a payload from Earth's surface into outer space. Reusable launch carrier rockets are designed to be recovered and launched again. The SpaceX Falcon 9 is the world's first partially-reusable launch system powered by rocket engines utilizing liquid propellants. This carrier rocket has a reusable first stage and an expendable second stage.

Falcon launches have two basic modes available. Reusable and expendable. In reusable mode, there is a fuel cost to brake the forward thrust, slow down for reentry through the atmosphere, and then finally for landing. Some amount of fuel must be reserved for stage recovery and cannot be used for thrust to orbit and therefore the functional payload is reduced.

Cost of carrier rocket launch can be mainly categorized in two parts:

1. Direct Cost
2. Indirect Cost

3.1 Analysis of the cost of launch Falcon carrier rocket

The launch price consists of cost of the carrier rocket and costs related to the start and landing, which are represented in particular by fuel costs, rocket transport, testing and others. In case of repeated use of the carrier, there is the cost of re-using and reducing the value of the rocket through wear, rebuilding and testing of the rocket for reuse as well as the cost of running the ASDS. The cost analysis of launching rockets with cargo under the aerodynamic cover is shown in Table 1.

Table 1. Analysis of the rocket launch cost

Price category:	*Cost component:*
Cost of carrier rocket:	Cost of First stage
	Cost of second stage
	Cost of aerodynamic fairing
Launch expenses:	Fuel
	Control centre services
	Launchpad services
	Transport services
	Testing
Costs for a reusable system:	Amortisation of reuse
	Refurbishment costs
	Operational costs for landing (Launchpad /ASDS)
	Transport service
	Testing

Table 2. Costs start at F9

	Assumed prize:
First stage as % of total direct costs (A)	(70%)
Second stage as % of total direct costs (B)	(15 – 20%)
Aerodynamic fairing cost (C)	(6*)
Cost of Merlin engine 1D+ (rough estimate)	∼1.5 (x 9)*
Cost of Merlin engine 1D vakuum (rough estimate)	∼1.6*
Selling price of Launch [6] (P)	62*

3.1.1 Cost of the Falcon carrier rocket

The price of the Falcon carrier rocket consists of first stage, second stage and aerodynamic fairing cost.

The price of the first stage consists of Merlin (9x), first stage fuselage, control, navigation and landing system, and tanks. The price of the Merlin rocket engine has not been published but it is estimated at $ 1,500,000 per piece. SpaceX manufacture most parts in-house, including engines, control and navigation systems.[3]

The price of the second stage consists of the Merlin engine (1x), the second stage fuselage , the control system and the tank. The costs are described in Table 2 and Table 3. Cost savings when it is reused the first stage is shown in Table 4.

3.1.2 Costs to start, landing and preparation costs for reuse

Start costs consist of fuel costs, delivery, inspection, testing, flight control, start ramp and live start broadcast costs. Landing costs and preparation for re-use consist of the costs of the stage refurbishment as well as the cost of the service landing ramp or ASDS and freight costs. A separate item of the cost of the start is insurance. Fuel and oxidiser are typically less than 0.3% of the launch price of the F9 carrier rocket.

Table 4 illustrates a model case of cost savings when it is reused the first stage. The model is just a demonstration of savings. Because of the complexity of the problem it can not display accurate values. Most of the values are based on the statements and materials released by SpaceX. Values are

Table 3. Costs start at F9

	Assumed prize:
Cost of first stage total (A)	30 – 40 (30)
Cost of second stage total (B)	7,5 – 12 (8)
Total cost of rocket (A+B+C)	44
Fuel costs	0,2 – 0,3 (0,2)
Rescue and Prepare Costs for Start (R)	8 - 15 (10)
Cost of launch operations (S)	4

Table 4. Savings model when reusing the first Falcon 9, the values are in millions of USD

	Falcon 9	F9 reuse
Cost of first stage (A —— R)	30	10
Cost of second stage (B)	8	8
Aerodynamic fairing cost (C)	6	6
Total cost of rocket (F)	44	24
Cost of launch operations (S)	4	4
Fuel costs (K)	0,2	0,2
Total cost of launch (N)=(F+S+K)	48,2	28,2
Margin (P–N)	13,8	33,8
Margin in %	22%	55%
Selling price of Launch F9 [6] (P)	62	62

excluding possible discounts. The actual values will be very individual in real cases depending on the specific conditions of the start. The model emphasizes direct costs and only necessarily essentials indirect costs are taken into account. Other indirect costs, such as insurance, make a separate chapter for each start.

3.1.3 Rescue and Prepare Costs for Start (R)

According to the company representatives SpaceX, in the case of the firsts re-use of the stages, re-use costs accounted less than half of the cost of production new stage[4]. The following versions of F9 have improved reuse capabilities. The incoming F9 Block 5 option is supposed to be capable of up to 10 starts without replacing parts. For the model, the price (R) is set at 1/3 of the price of the new stage (A). It can be expected that there will be an expansion of reusability and optimizations related processes that will represent a further cost reduction.[5]

Table 5 shows the profit growth of around 30%, which corresponds to the values that were mentioned in this context representatives of SpaceX. Values also correspond to some published discounts from the start price.

In the case of the heavy Falcon Heavy carrier rocket, even more significant savings can be expected, as shown in Table 6. FH rocket builds on the standard Falcon 9 rocket, complemented by two auxiliary rocket stages. The auxiliary stages are also basically modified the first stages of the Falcon 9. From the point of view of re-use, there are basically three first stages of the F9 rocket, which start together and then land independently.[6]

Table 5. Falcon Heavy reuse model, values in millions USD

	Falcon Heavy	FH reuse
Cost of first stage (3 x A —— 3 x R)	90	30
Cost of second stage (B)	8	8
Aerodynamic fairing cost (C)	6	6
Total cost of rocket (F)	104	44
Cost of launch operations (S)	4	4
Fuel costs (K)=(∼3xK)	0,6	0,6
Total cost of launch (N)=(F+S+K)	108,6	48,6
Margin (P–N)	-18,6	41,4
Margin in %	-21%	46%
Selling price of Launch FH [6] (P)	90	90

For heavy Falcon Heavy rocket launchers, table 6 shows a rise in re-usability importance. There is a clear difference in start-up costs for the expendable variant versus the reusable variant. This is not surprising, as there is a 3 stage rescue, compared to one at F9. A expendable option has costs clearly exceeding the table price for the start. In this configuration, the start would be a loss. In reality, the difference would probably be even greater because the model calculates with lower prices for individual items. SpaceX is now fully reliant on FH for reusability.[7] Considering an impressive load of 63 800 kg to LEO, this step is understandable. It can also be expected that in the case of demanding start run without rescue, the starting price will probably be above the table price. The purpose of this analysis was to demonstrate the importance of reusability for the Falcon Heavy carrier rocket.

4. Conclusion

The long-term vision and goal of the space industry is to create a launch vehicle that is capable of delivering fast, safe, reliable and relatively inexpensive launch to the space. Reusability is a response to these requirements. I believe that reusability will have a significant impact on cosmonautics over the next few decades, and it will become a matter of course within a few decades. In my opinion, re-usable means are now the phenomenon of the time in cosmonautics. Just recovering only the first stage of a Falcon 9 for reuse on multiple flights would allow SpaceX to significantly lower the price of launches for satellites and supply or crewed spacecraft.

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