BACK TO THE EARTH

I vettori a rientro controllato

“A jumbo jet costs about the same as one of our Falcon 9 rockets, but airlines don't junk a plane after a one-way trip from LA to New York. Yet when it comes to space travel, rockets fly only once - even though the rocket itself represents the majority of launch cost.” ~ Elon Musk

SpaceX - Falcon 9

Blue Origin – New Shepard

China Academy of Launch Vehicle Technology - LM 2C

Rocket Lab – Electron

SPACEX

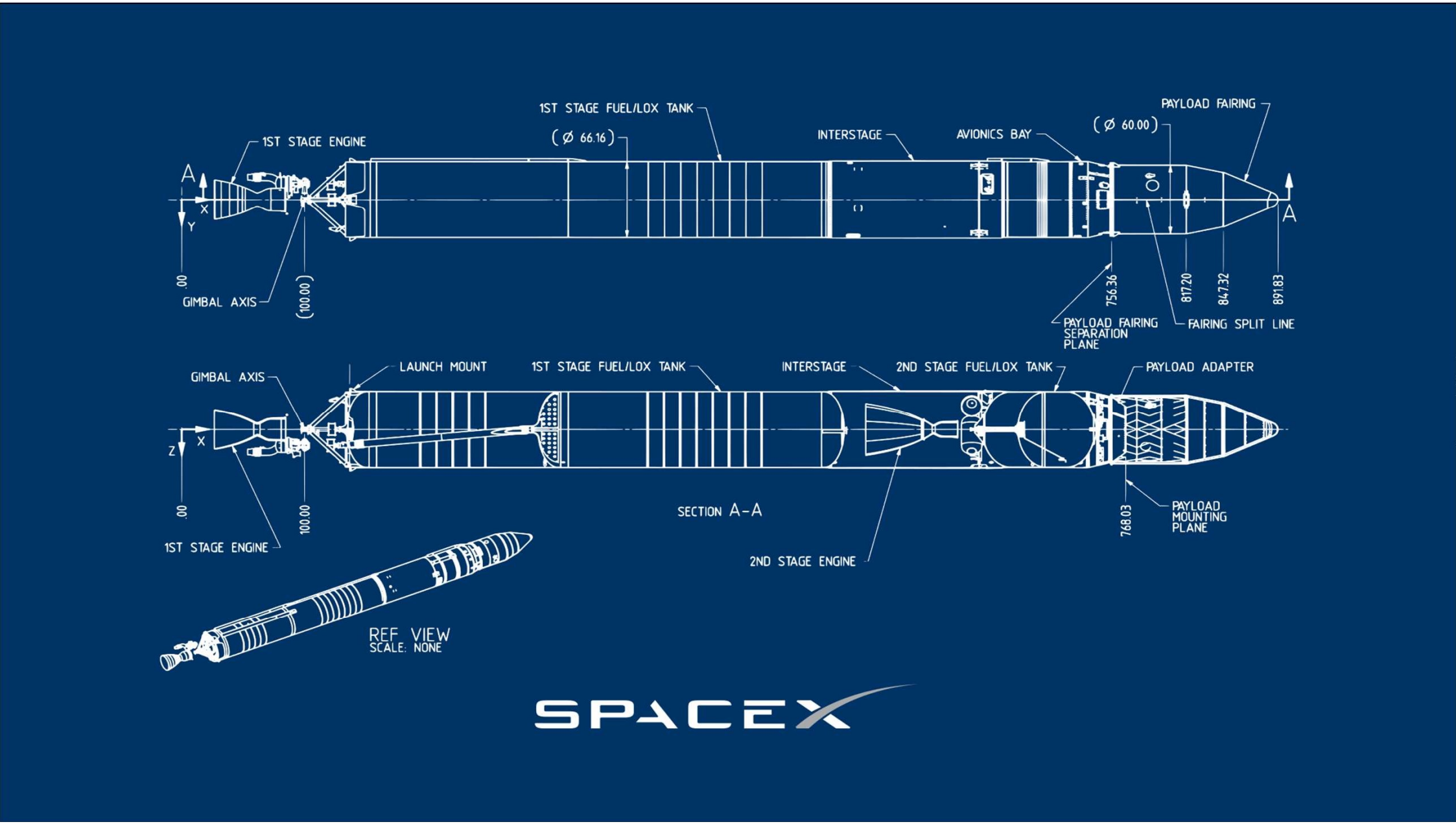
ELON MUSK

SPACEX – QUALCHE NUMERO…

- Fondazione: 06/05/2002
- 7000 dipendenti (2018)
- 33,3 miliardi $ di fatturato nel giugno 2019
- 3 lanciatori e 2 veicoli orbitali
- 3 siti di lancio
- 4 siti per il recupero di vettori (3 operativi)

I FALCHI DI SPACEX

I FALCHI DI SPACEX – FALCON 1


1ST STAGE ENGINE
1ST STAGE FUEL/LOX TANK
(Ø 66.16)
INTERSTAGE
AVIONICS BAY
(Ø 60.00)
PAYLOAD FAIRING
A
X
Y
.00
GIMBAL AXIS
(100.00)
756.36
817.20
847.32
891.83
PAYLOAD FAIRING SEPARATION PLANE
FAIRING SPLIT LINE
A
GIMBAL AXIS
LAUNCH MOUNT
1ST STAGE FUEL/LOX TANK
INTERSTAGE
2ND STAGE FUEL/LOX TANK
PAYLOAD ADAPTER
Z
X
.00
100.00
SECTION A-A
768.03
PAYLOAD MOUNTING PLANE
1ST STAGE ENGINE
2ND STAGE ENGINE
REF. VIEW
SCALE: NONE
SPACEX

I FALCHI DI SPACEX – GLI EREDI DI FALCON 1

- Falcon 1e

- Falcon 5

I FALCHI DI SPACEX – FALCON 9

- Volo inaugurale: 4 giugno 2010
- Primo atterraggio perseguito con successo: 22 dicembre 2015
- Cinque versioni
  1. 1.0
  2. 1.1
  3. Full Thrust
  4. Block 4
  5. Block 5

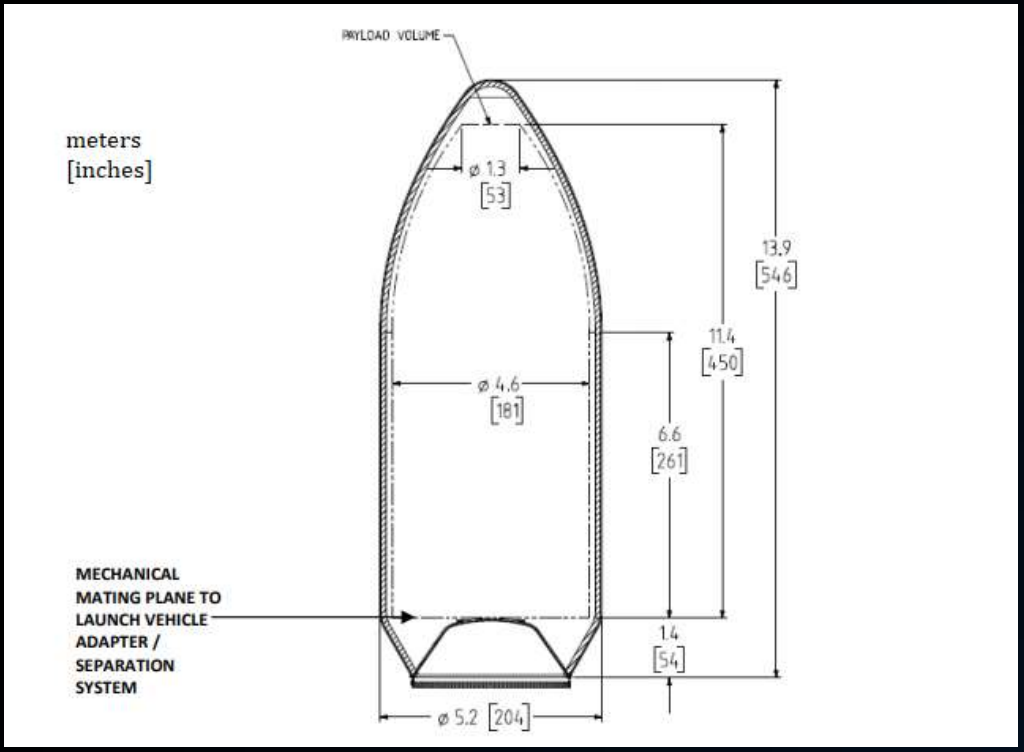
GLI STADI DEL FALCON 9

Il Falcon 9 è composto da 4 elementi:

1. **PAYLOAD**
2. **SECOND STAGE**
3. **INTERSTAGE**
4. **FIRST STAGE**

FALCON 9 – IL PAYLOAD

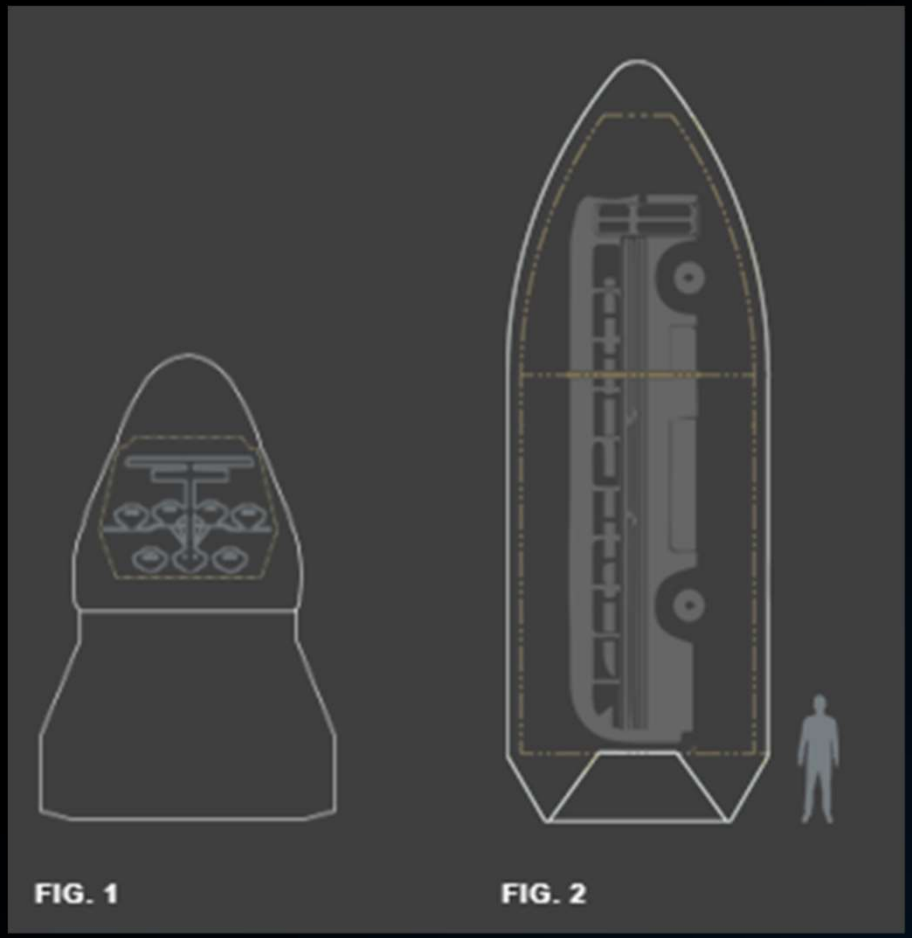
- Carenatura
  (materiale composito)



FALCON 9 – IL PAYLOAD

- Dragon
- Dragon Crew

FALCON 9 – IL PAYLOAD



FALCON 9 – IL PAYLOAD

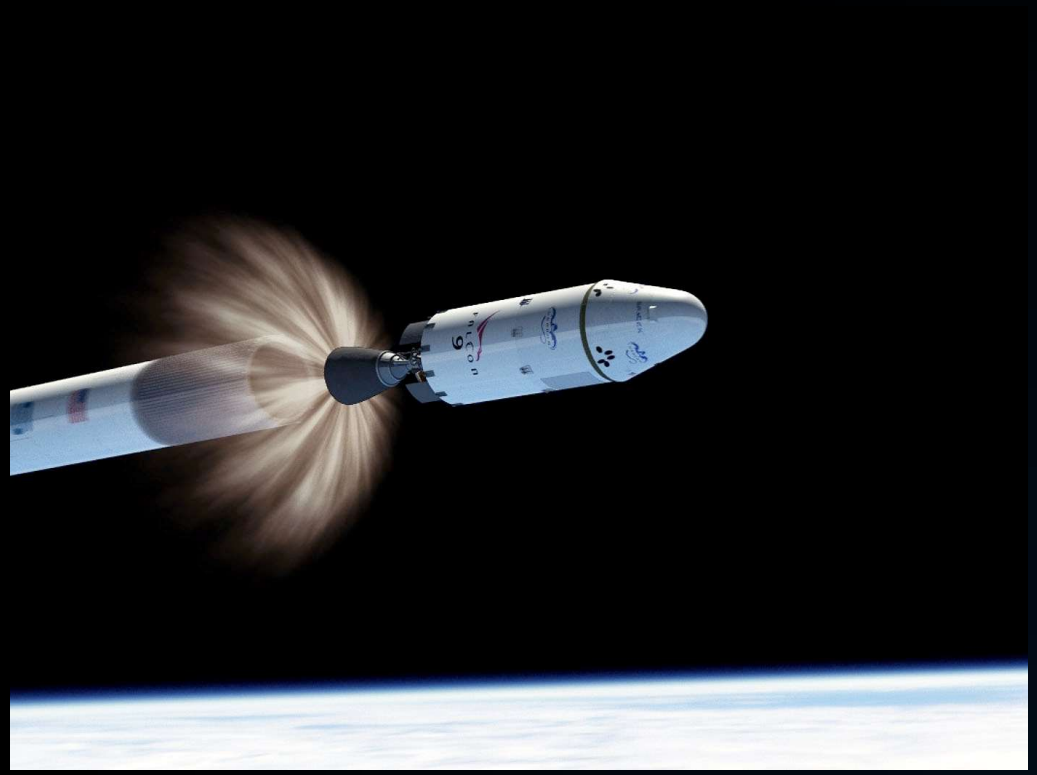
FALCON 9 – SECOND STAGE

- **UTILIZZO:** Trasporto del payload (LEO, GTO, GSO and outer space)
- **MATERIALE TELAIO:** Lega di Al-Li ad elevata resistenza
- **MOTORE:** SpaceX Merlin Vacuum Engine (1D+)
  - N.° di motori (2nd Stage): 1
  - Accensioni multiple
  - Spinta: 934 kN
  - Impulso specifico: 348 s
  - Tempo di accensione: 397 s (6 m 37 s)
  - Peso: 490 Kg
  - Diametro: 1.25 m
  - Pressione nella c.d.c.: 9,7 Mpa
  - Regolazione della potenza (39-100%)

FALCON 9 – INTERSTAGE

- Elemento di congiunzione tra primo e secondo stadio
- Al suo interno si trova il motore del 2nd stage
- Tecnologia:
  - Materiale composito
  - Sistema di separazione interamente pneumatico, altamente affidabile e testabile a terra

FALCON 9 – SECOND STAGE SEPARATION

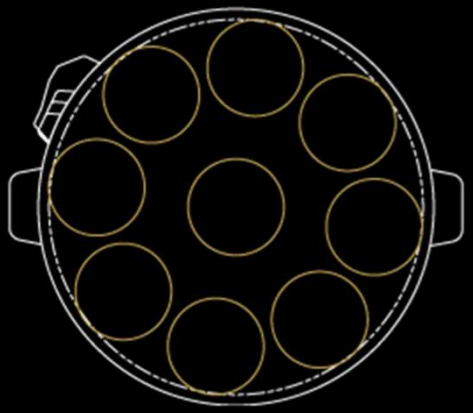


FALCON 9 – FIRST STAGE

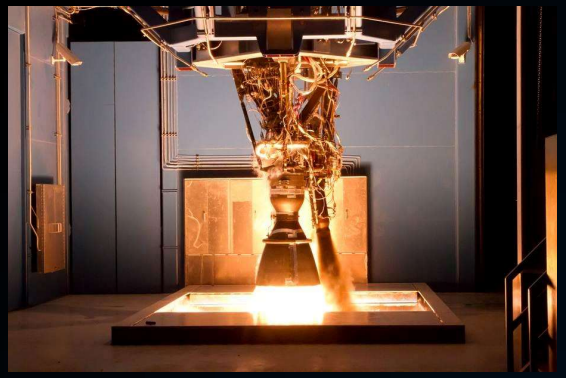
- **UTILIZZO:** Lanciatore riutilizzabile
- **MATERIALE TELAIO:** Lega di Al-Li ad elevata resistenza
- **MOTORE:** SpaceX Merlin Engine (1D+)
  - N.° di motori (1st Stage): 9
  - Spinta: 845 kN per motore (7607 tot.) (s.l.), 914 kN per motore (8227 tot.) (vacuum)
  - Impulso specifico: 282 s (s.l.), 314 s (vacuum)
  - Tempo di accensione: 162 s (2 m 42 s)
  - Peso: 470 Kg
  - Diametro: 1.25 m
  - Pressione nella c.d.c.: >10 Mpa
  - Regolazione della potenza (55-100%)

Il primo stadio è in grado di volare anche con 2 motori non funzionanti.

FALCON 9 – FIRST STAGE: ENGINES



Octaweb configuration



FALCON 9 – FIRST STAGE: ENGINES

PROPELLENTE: Ossigeno liquido/RP-1
VERSIONI: 1A, 1B, 1C, 1D, 1D+ (Vacuum versions: 1C Vac, 1D Vac, 1D+ Vac)

SPINTA (kN)

ENGINE	1A	1B	1C	1D	1D+
Merlin (s.l./v.)	342/408	n.d.	420/480	645/716	845/914
Merlin Vacuum	n.d.	n.d.	445	801	914

IMPULSO SPECIFICO (s)

ENGINE	1A	1B	1C	1D	1D+
Merlin (s.l./v.)	255/304	n.d.	275/304	282/311	282/314
Merlin Vacuum	n.d.	n.d.	342	340	348

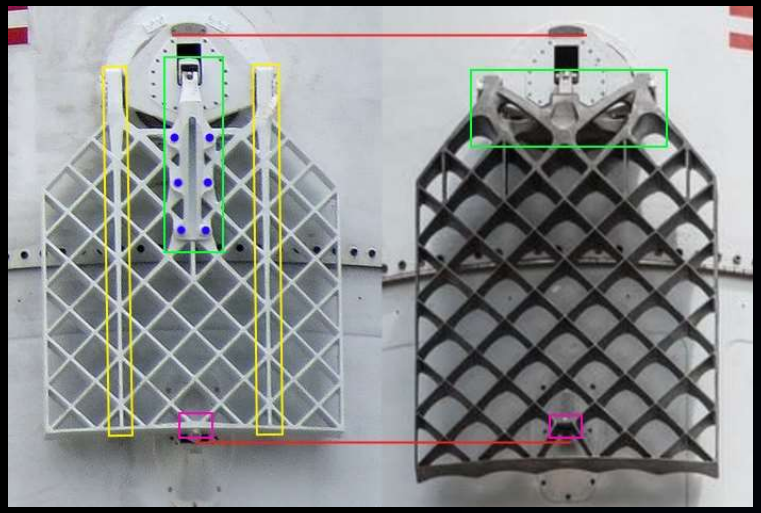
FALCON 9 – FIRST STAGE: FINS

FALCON 9 – FIRST STAGE: FINS

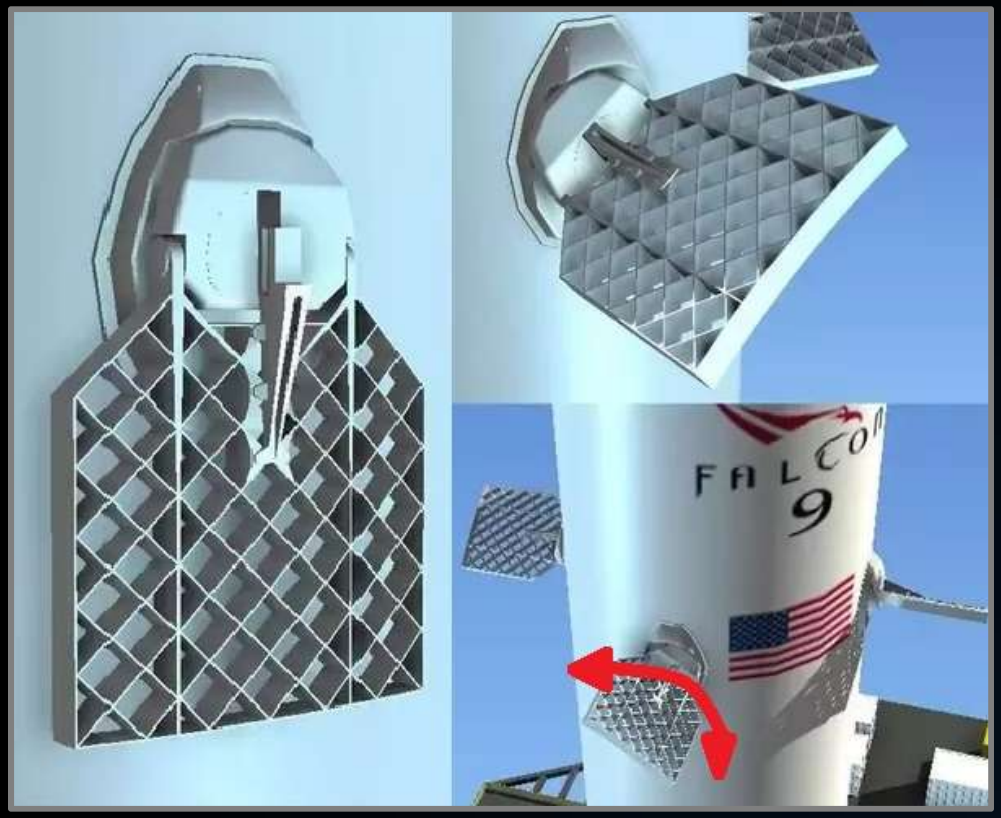
Sviluppate dell'ingegnere russo Sergey Belotserkovskiy negli anni '50

Grid fins del Falcon 9:

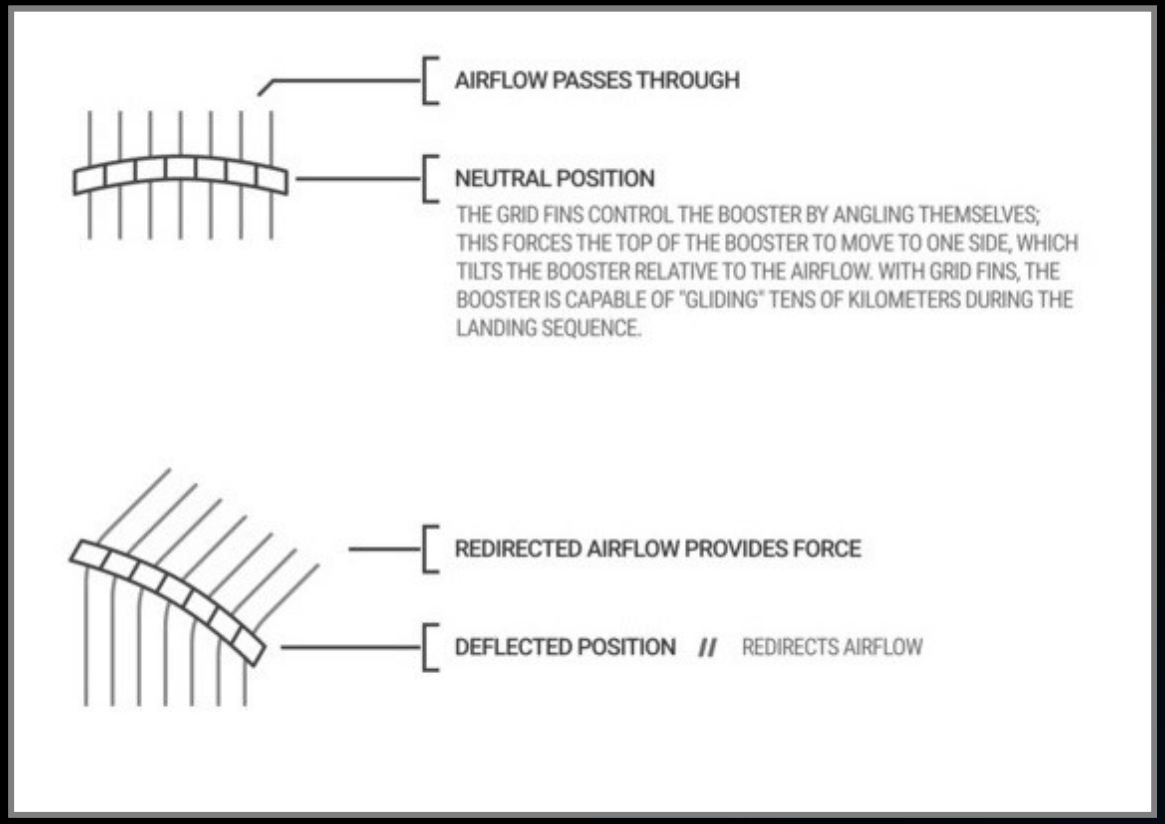
- **MATERIALE:** alluminio (MOD 1, MOD 2, MOD 3), titanio (MOD 4)
- **DIMENSIONI:** 1.2 x 1.5 m (MOD 3)

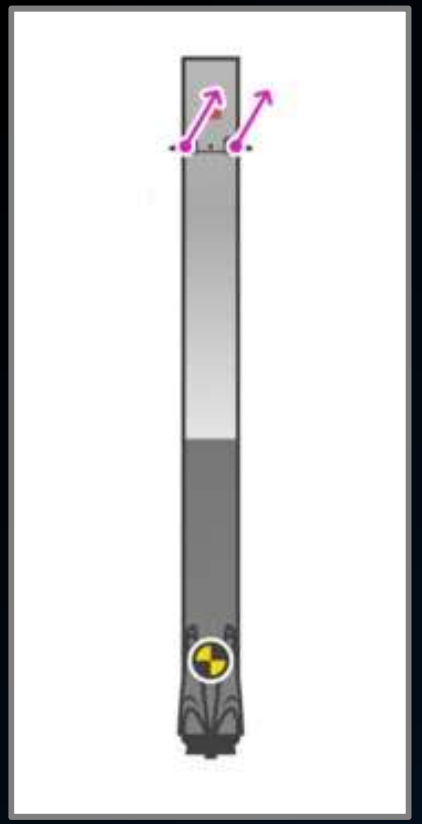


FALCON 9 – FIRST STAGE: FINS

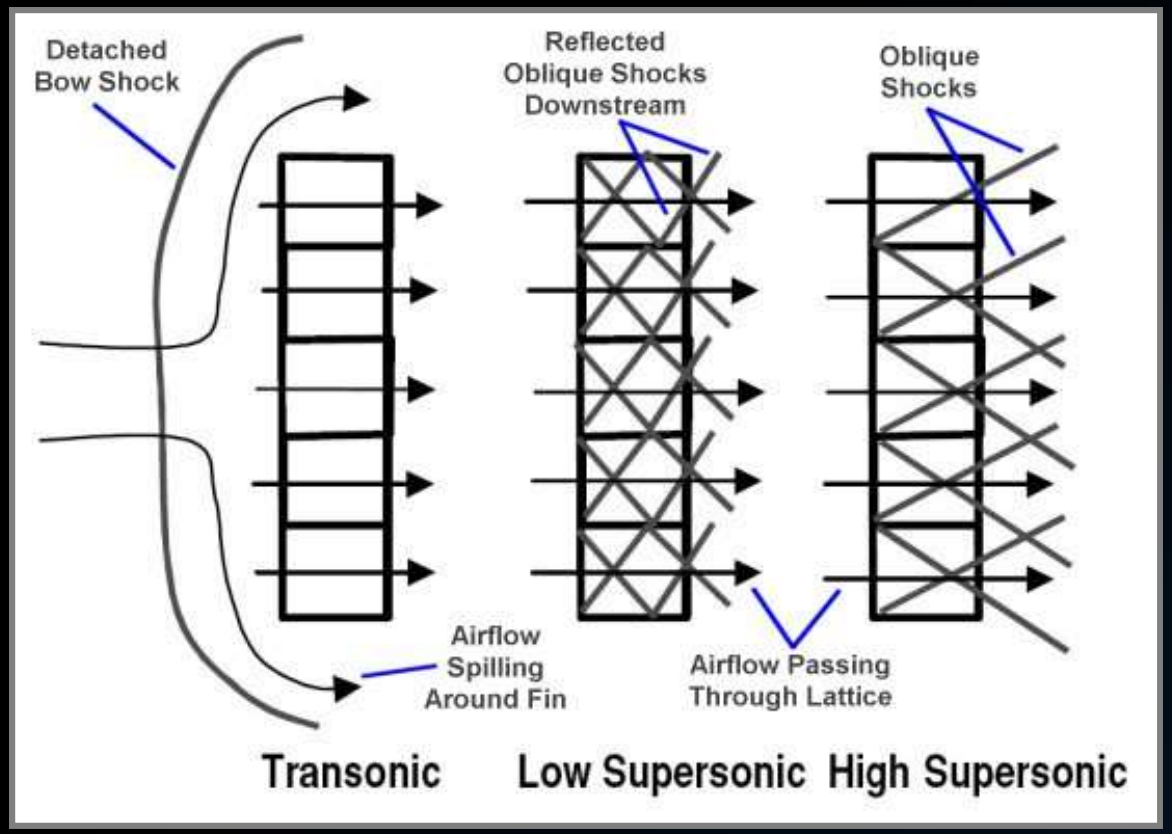


FALCON 9 – FIRST STAGE: FINS





FALCON 9 – FIRST STAGE: FINS

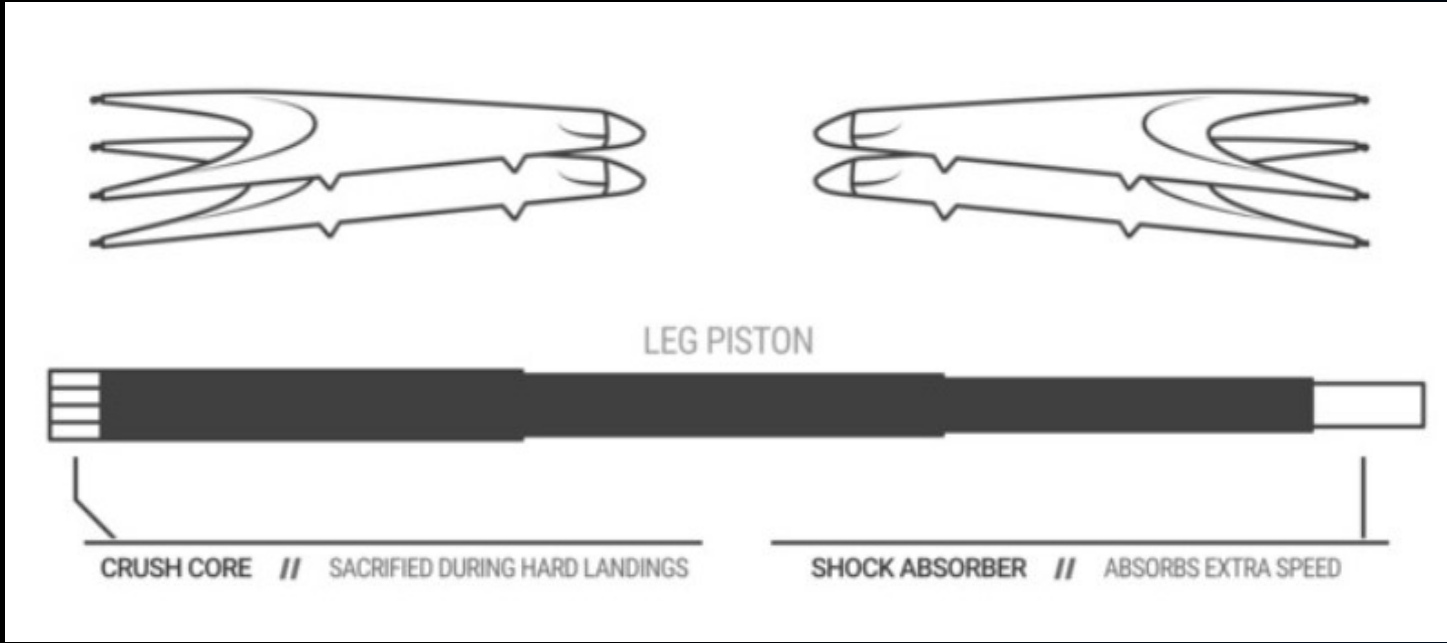


FALCON 9 – FIRST STAGE: LANDING LEGS

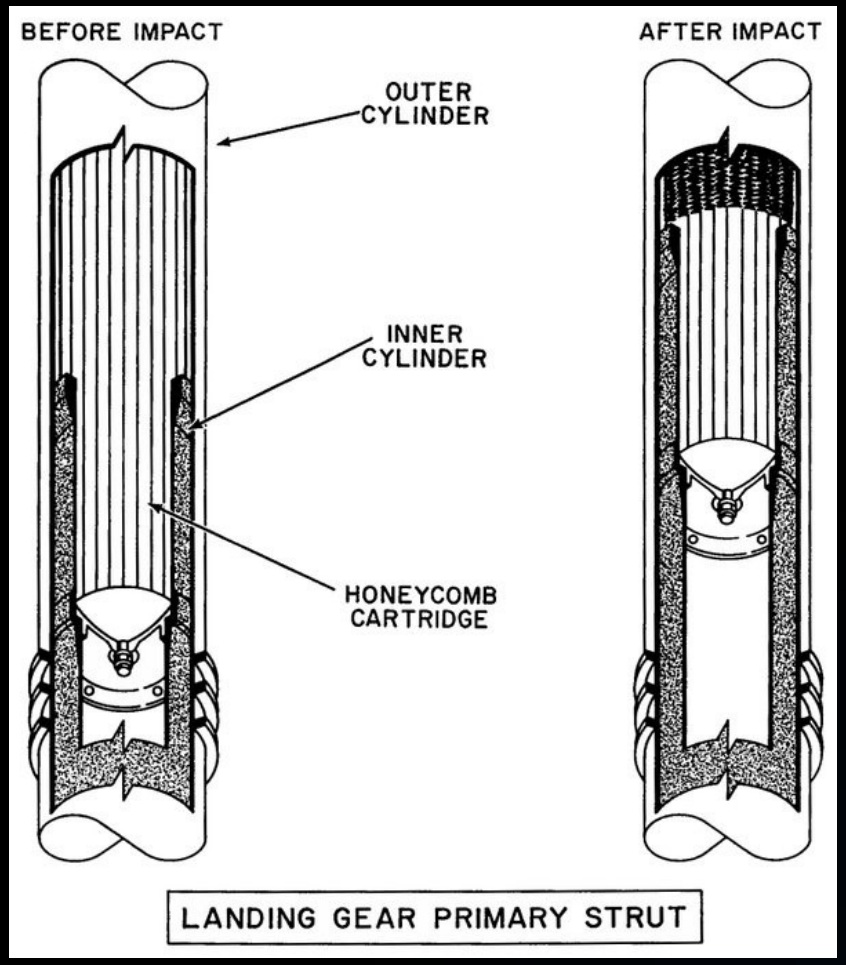
FALCON 9 – FIRST STAGE: LANDING LEGS

Si tratta di un **meccanismo a glifo**

ELEMENTI: attuatore, pistone, gambe, fermi
ATTUATORE: sistema pneumatico con He_2 ad alta pressione
MATERIALE: Fibra di carbonio, alluminio in configurazione a nido d'ape (**crush core**)

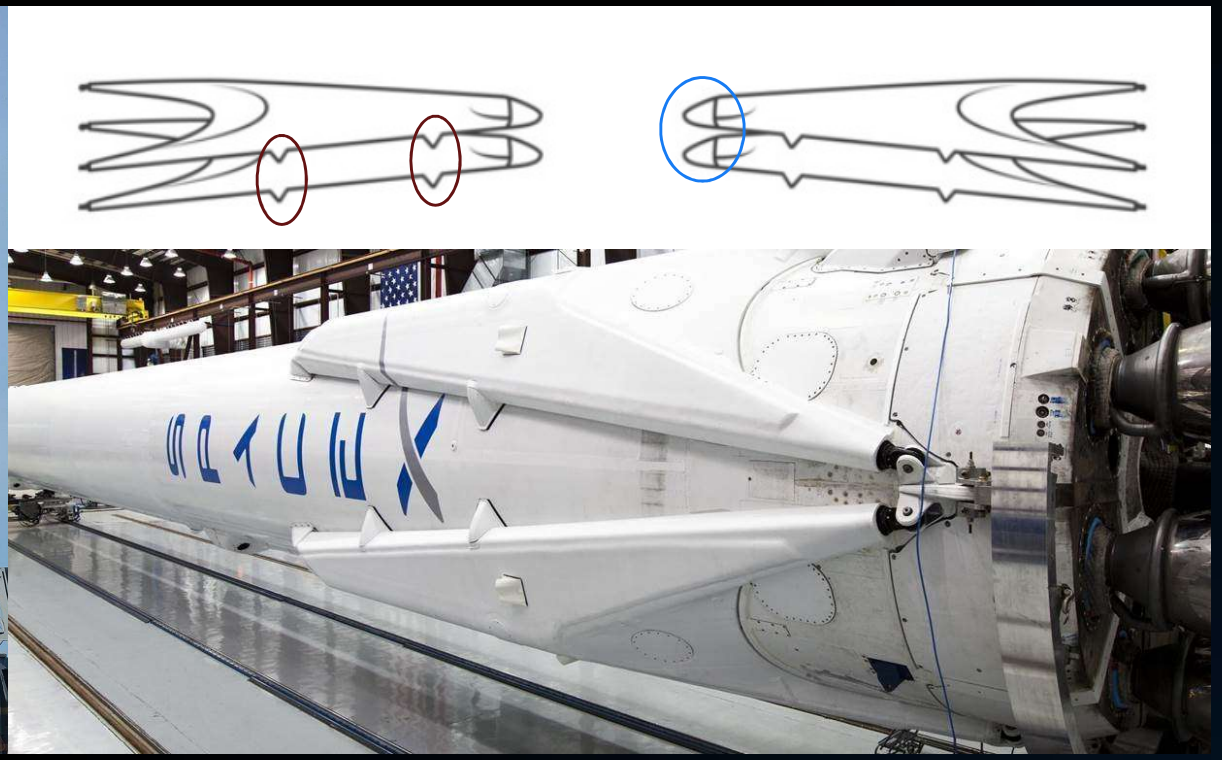


FALCON 9 – FIRST STAGE: LANDING LEGS



Il crush core in alluminio assorbe i grossi impatti

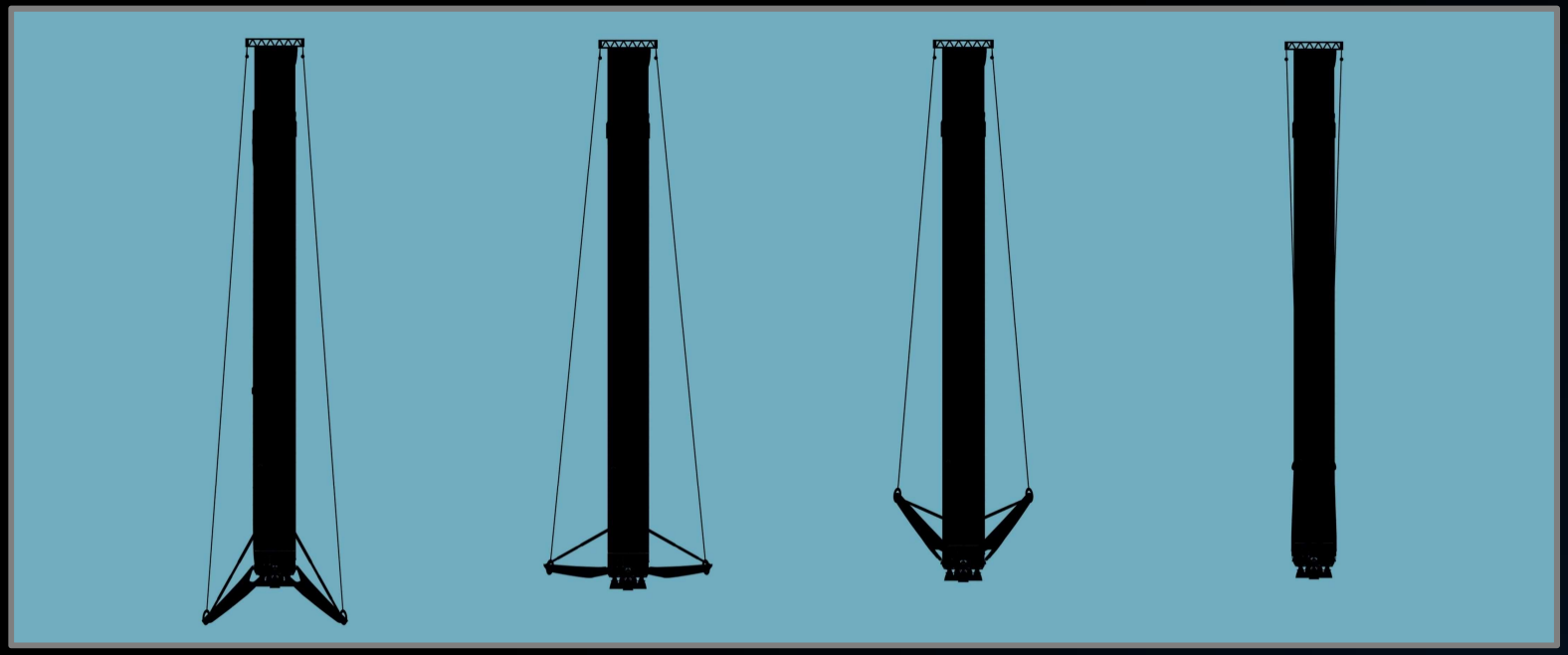
FALCON 9 – FIRST STAGE: LANDING LEGS



I fermi assicurano le landing legs al telaio del lanciatore

FALCON 9 – FIRST STAGE: LANDING LEGS

Procedura di riallocamento delle landing legs



SpaceX Falcon 9 // TRANSPORT

* AS OF AUGUST 2016

ALL OF THE COMPONENTS FOR THE FALCON 9 ARE SHIPPED TO THE LAUNCH SITE ON U.S. HIGHWAYS. THE FALCON 9 WAS DESIGNED FROM THE START TO FIT U.S. ROADS.

DURING THE TRANSPORTATION OF FALCON 9 STAGES, THEY ARE PRESSURIZED WITH NITROGEN AND COVERED IN A CUSTOM-MADE BLACK PLASTIC WRAP TO KEEP THEM CLEAN AND FREE OF FOREIGN OBJECTS.

STAGE TWO

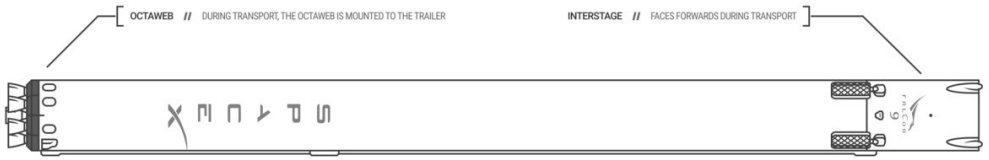
IT IS NOT PUBLICLY KNOWN WHAT COMPONENTS ARE ATTACHED TO THE SECOND STAGE DURING TRANSPORTATION.

FAIRINGS

THE FAIRINGS ARE TRANSPORTED INDEPENDENTLY TO THE LAUNCHSITE, WHERE THE SATELLITE IS MATED TO THE PAYLOAD ADAPTER AND THE FAIRINGS ARE ATTACHED, ENCAPSULATING THE PAYLOAD IN PREPARATION FOR LAUNCH.

LANDING LEGS

THE LANDING LEGS ARE TRANSPORTED INDEPENDENTLY TO THE LAUNCH SITE AND INSTALLED ON THE STAGE THERE.



STAGE ONE

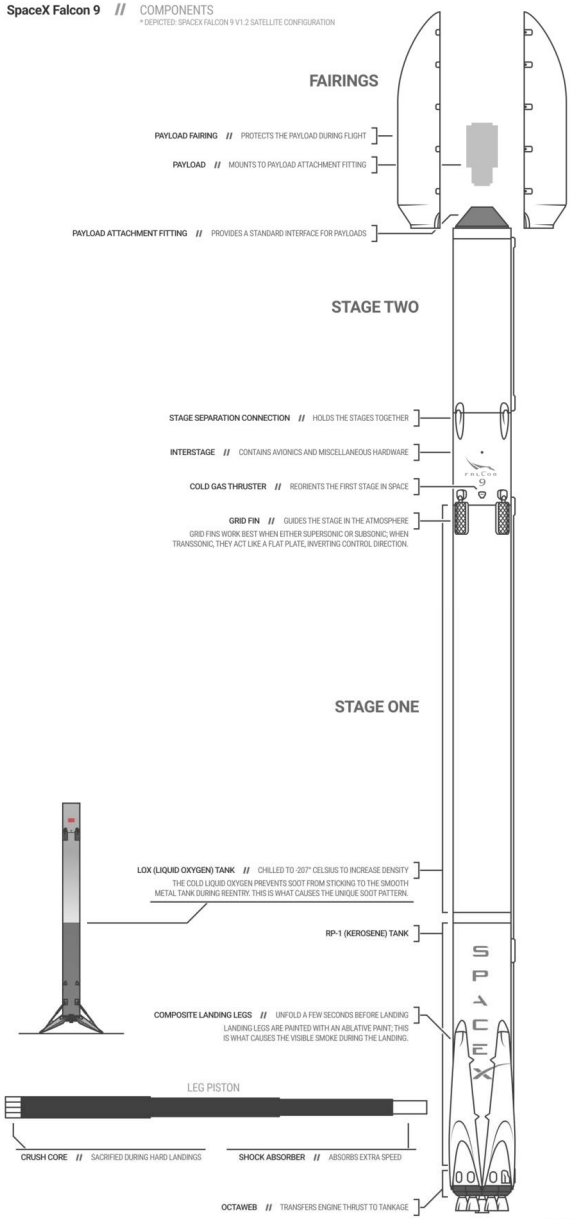
TECHNICAL OVERVIEW

HEIGHT	MASS	PAYLOAD TO LEO	PAYLOAD TO MARS
70 m 229.6 ft	549,054 kg 1,207,920 lb	22,800 kg 50,265 lb	4,020 kg 8,860lb

DIAMETER	STAGES	PAYLOAD TO GTO
3.7 m 12 ft	2	8,300 kg 18,300 lb

SpaceX Falcon 9 // COMPONENTS

* DEPICTED: SPACEX FALCON 9 V1.2 SATELLITE CONFIGURATION



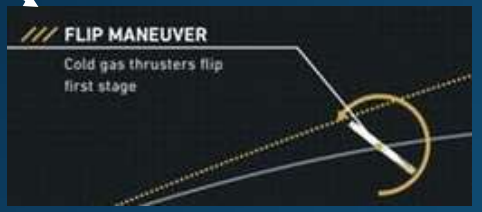
FALCON 9 – LA FASE DI ATTERRAGGIO

I sistemi che consentono il controllo del Falcon 9 in fase di atterraggio sono:

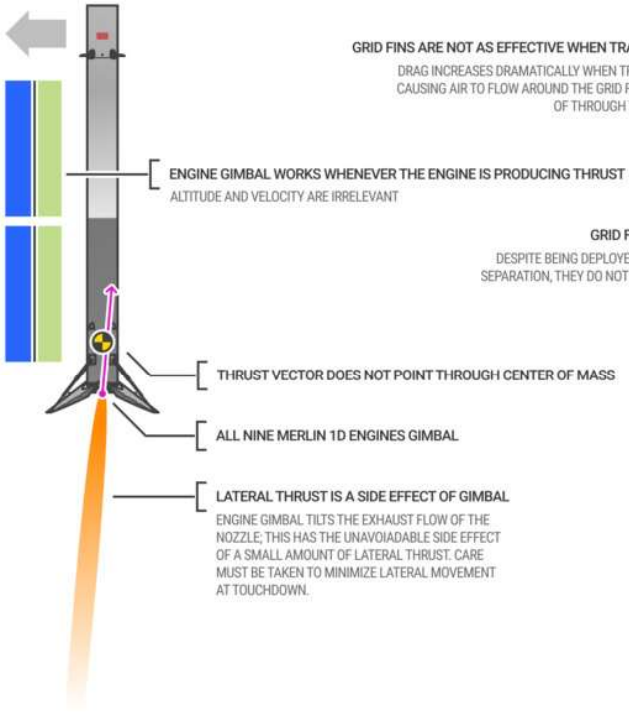
- Motore principale
- Alette a griglia (grid fins)
- RCS (Reaction control system):
  - Cold Gas Thrusters (propellente: N_2)
  - Funziona sia nel vuoto che nell'atmosfera
  - Vengono utilizzati sia nella prima fase di rientro, sia nella fase finale di atterraggio

FALCON 9 – LA FASE DI ATTERRAGGIO

- **FASE 1:** manovra di flip (rotazione di 180° attorno all'asse trasversale) ⟶ RCS
- **FASE 2:** incurvamento della traiettoria ⟶ Motori principali
- **FASE 3:** rientro atmosferico ⟶ Grid fins (numero di Mach > 3)
- **FASE 4:** avvicinamento ⟶ Tutti e tre i sistemi sono in azione
- **FASE 5:** dispiegamento delle landing legs
- **FASE 6:** atterraggio morbido ($V \approx 6\,m/s$)



ENGINE GIMBAL



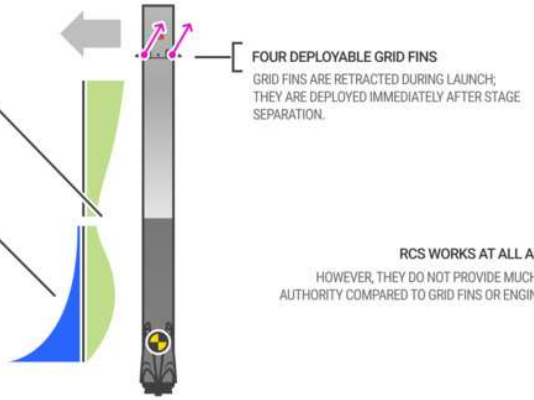
ENGINE GIMBAL WORKS WHENEVER THE ENGINE IS PRODUCING THRUST
ALTITUDE AND VELOCITY ARE IRRELEVANT

THRUST VECTOR DOES NOT POINT THROUGH CENTER OF MASS

ALL NINE MERLIN 1D ENGINES GIMBAL

LATERAL THRUST IS A SIDE EFFECT OF GIMBAL
ENGINE GIMBAL TILTS THE EXHAUST FLOW OF THE NOZZLE; THIS HAS THE UNAVOIADABLE SIDE EFFECT OF A SMALL AMOUNT OF LATERAL THRUST. CARE MUST BE TAKEN TO MINIMIZE LATERAL MOVEMENT AT TOUCHDOWN.

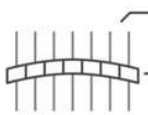
GRID FINS



GRID FINS ARE NOT AS EFFECTIVE WHEN TRANSSONIC
DRAG INCREASES DRAMATICALLY WHEN TRANSSONIC, CAUSING AIR TO FLOW AROUND THE GRID FIN INSTEAD OF THROUGH THE HOLES.

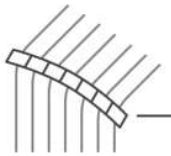
GRID FINS ONLY OPERATE IN AIR
DESPITE BEING DEPLOYED IMMEDIATELY AFTER STAGE SEPARATION, THEY DO NOT BEGIN TO TAKE EFFECT UNTIL ENTERING THE ATMOSPHERE.

FOUR DEPLOYABLE GRID FINS
GRID FINS ARE RETRACTED DURING LAUNCH; THEY ARE DEPLOYED IMMEDIATELY AFTER STAGE SEPARATION.



AIRFLOW PASSES THROUGH

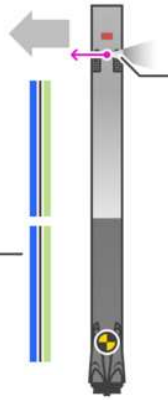
NEUTRAL POSITION
THE GRID FINS CONTROL THE BOOSTER BY ANGLING THEMSELVES; THIS FORCES THE TOP OF THE BOOSTER TO MOVE TO ONE SIDE, WHICH TILTS THE BOOSTER RELATIVE TO THE AIRFLOW. WITH GRID FINS, THE BOOSTER IS CAPABLE OF "GLIDING" TENS OF KILOMETERS DURING THE LANDING SEQUENCE.



REDIRECTED AIRFLOW PROVIDES FORCE

DEFLECTED POSITION // REDIRECTS AIRFLOW

NITROGEN RCS



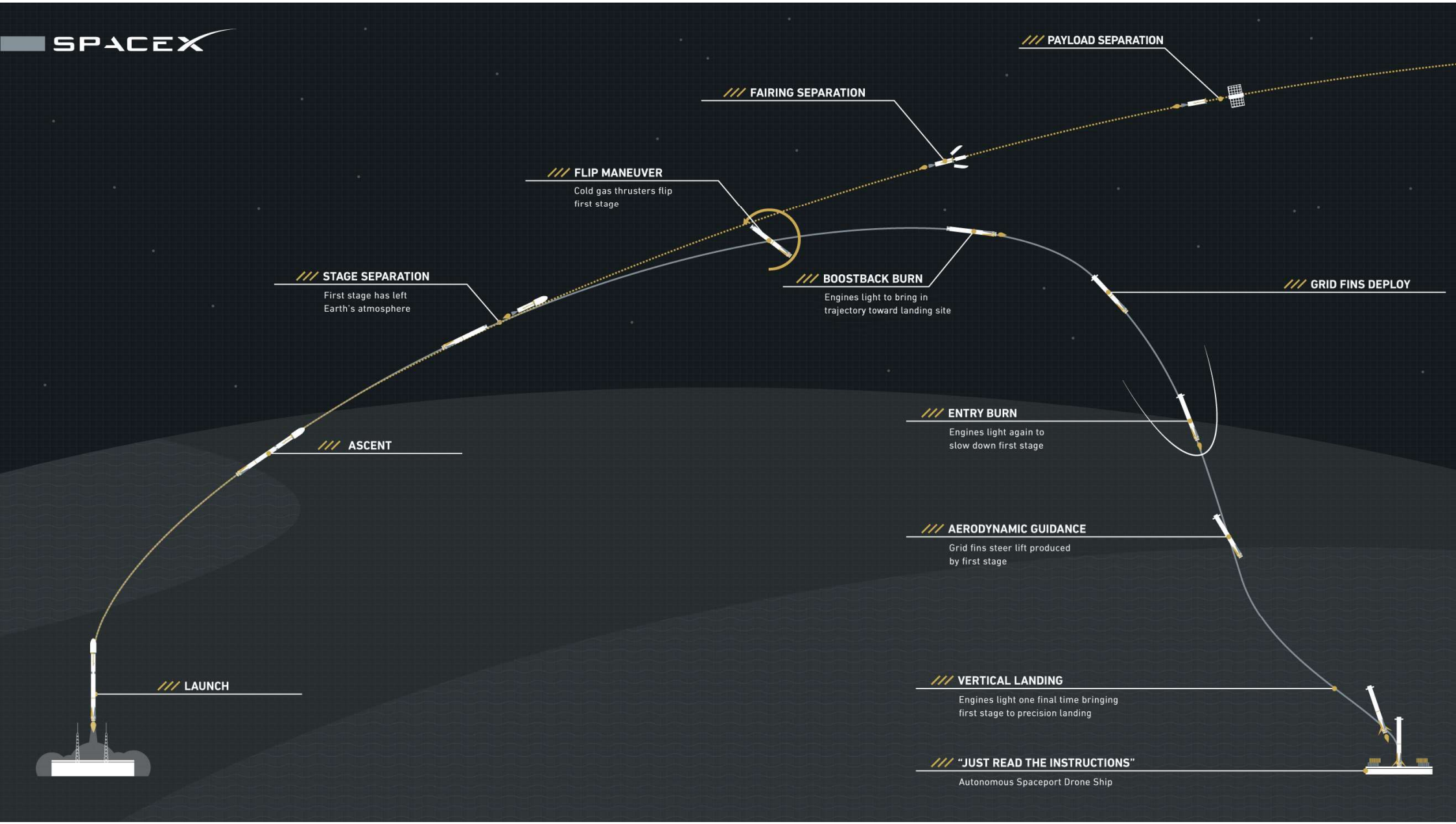
REACTION CONTROL SYSTEM WORKS IN SPACE
UNLIKE GRID FINS, WHICH ONLY WORK IN AN ATMOSPHERE, RCS WORKS IN A VACUUM. HOWEVER, RCS REQUIRES A PROPELLANT, WHICH IS EXPENDED; IN ADDITION, REACTION CONTROL SYSTEMS ARE NOT NEARLY AS POWERFUL AS GRID FINS.

RCS WORKS AT ALL ALTITUDES
HOWEVER, THEY DO NOT PROVIDE MUCH CONTROL AUTHORITY COMPARED TO GRID FINS OR ENGINE GIMBAL.

KEY

FORCE VECTOR

CENTER OF MASS


SPACEX
PAYLOAD SEPARATION
FAIRING SEPARATION
FLIP MANEUVER
Cold gas thrusters flip first stage
STAGE SEPARATION
First stage has left Earth's atmosphere
BOOSTBACK BURN
Engines light to bring in trajectory toward landing site
GRID FINS DEPLOY
ENTRY BURN
Engines light again to slow down first stage
ASCENT
AERODYNAMIC GUIDANCE
Grid fins steer lift produced by first stage
LAUNCH
VERTICAL LANDING
Engines light one final time bringing first stage to precision landing
"JUST READ THE INSTRUCTIONS"
Autonomous Spaceport Drone Ship

FALCON 9 – IL PRIMO ATTERRAGGIO

I FALCHI DI SPACEX – FALCON HEAVY

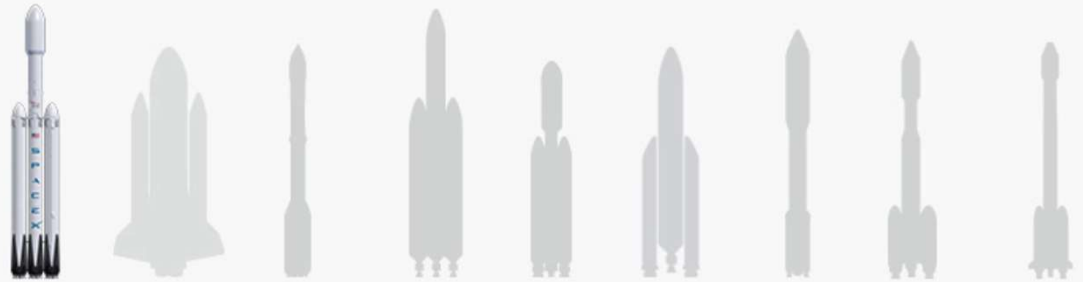
Il Falcon Heavy è un vettore super-pesante, il cui core centrale è un razzo Falcon 9; il Falcon Heavy è però equipaggiato con due primi stadi del Falcon 9 aggiuntivi che hanno il ruolo di booster laterali nella prima fase della missione

FALCON HEAVY

TECHNICAL OVERVIEW

HEIGHT	STAGES	BOOSTERS	PAYLOAD TO LEO	PAYLOAD TO MARS
70 m 229.6 ft	**2**	**2**	**63,800 kg** 140,660 lb	**16,800 kg** 37,040 lb

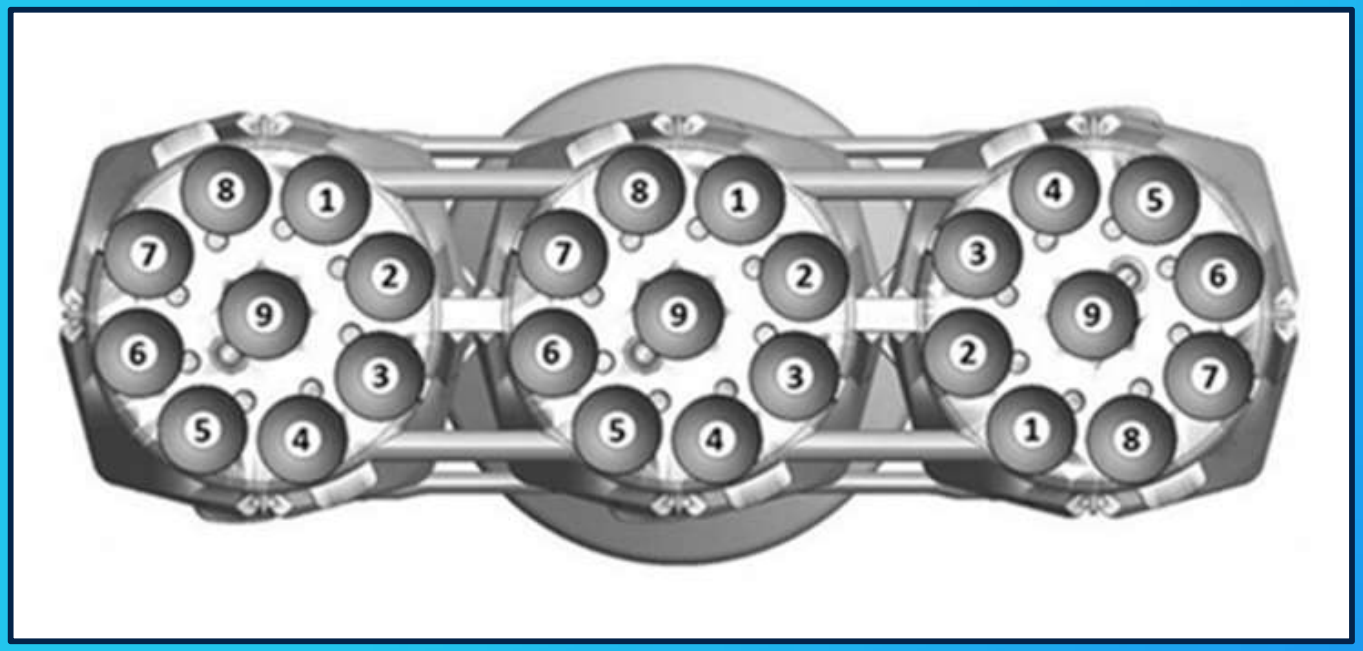
TOTAL WIDTH	MASS	PAYLOAD TO GTO	PAYLOAD TO PLUTO
12.2 m 39.9 ft	**1,420,788 kg** 3,125,735 lb	**26,700 kg** 58,860 lb	**3,500 kg** 7,720 lb



LAUNCH VEHICLE	FALCON HEAVY	SPACE SHUTTLE	PROTON M	DELTA IV HEAVY	TITAN IV-B	ARIANE 5 ES	ATLAS V 551	JAPAN H2B	CHINA LM3B
PAYLOAD TO LOW EARTH ORBIT (LEO)	63,800 kg 140,660 lb	24,000 kg 53,790 lb	23,000 kg 50,710 lb	22,560 kg 49,740 lb	21,680 kg 47,800 lb	20,000 kg 44,090 lb	18,510 kg 40,810 lb	16,500 kg 36,380 lb	11,200 kg 24,690 lb

FALCON HEAVY

- 27 motori
- Sea Level: 22819 kN
- Vacuum: 24681 kN



FALCON HEAVY

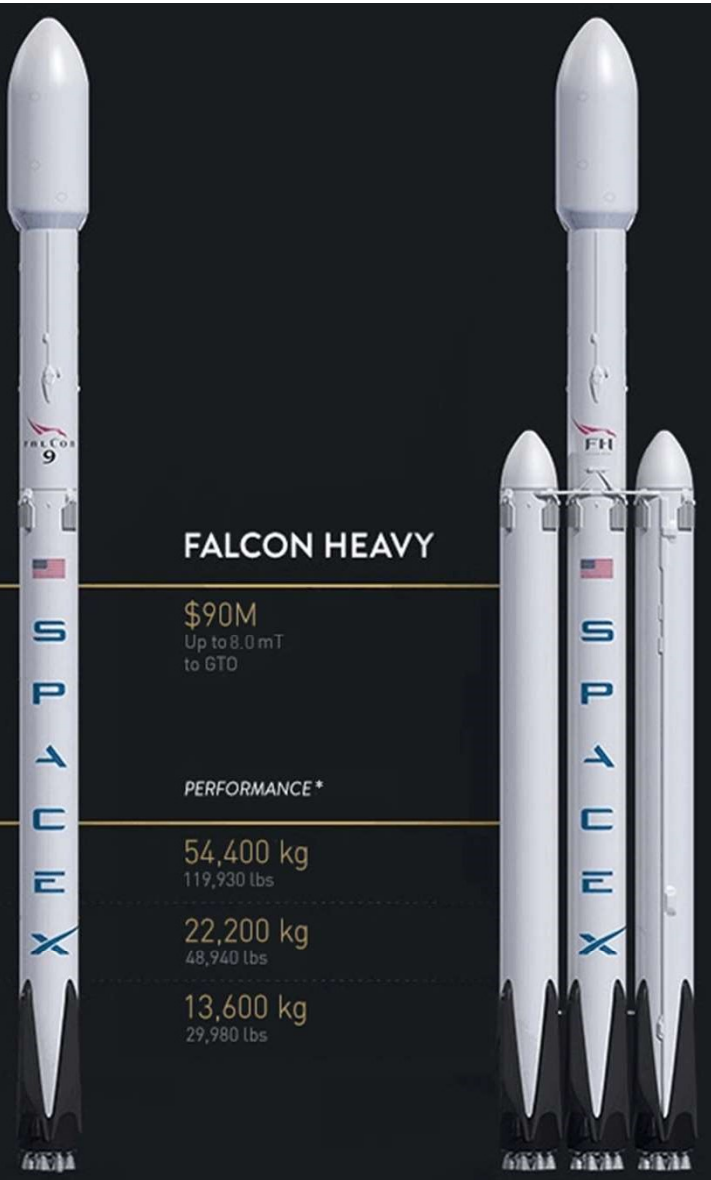
- **VOLO INAUGURALE:** 6 febbraio 2018 alle 15:45 (ora locale)
- **ATTERRAGGIO CORE LATERALI:** Riuscito (terraferma)
- **ATTERRAGGIO CORE CENTRALE:** Fallito (atterraggio previsto sulle ASDS, il core si è schianto in mare)
- **PAYLOAD:** Tesla Roadster, diretta verso Marte

CAPABILITIES & SERVICES

SpaceX offers open and fixed pricing for its Falcon 9 and Falcon Heavy launch services. Modest discounts are available, for contractually committed, multi-launch purchases. SpaceX can also offer crew transportation services to commercial customers seeking to transport astronauts to alternate LEO destinations.

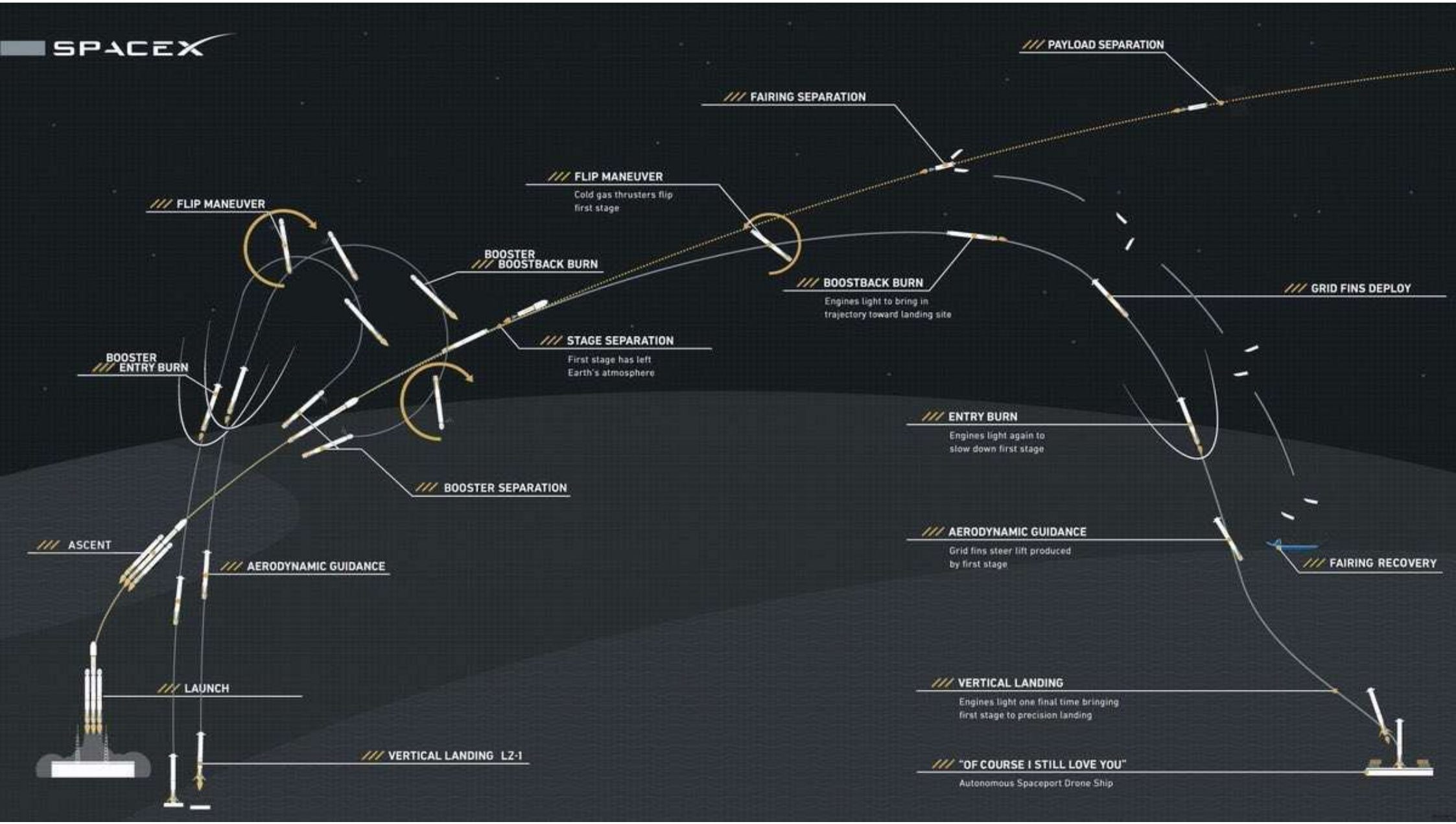
PRICE	FALCON 9	FALCON HEAVY
STANDARD PAYMENT PLAN (2018 LAUNCH)	$62M Up to 5.5 mT to GTO	$90M Up to 8.0 mT to GTO

DESTINATION	*PERFORMANCE**	*PERFORMANCE**
LOW EARTH ORBIT (LEO)	22,800 kg 50,265 lbs	54,400 kg 119,930 lbs
GEOSYNCHRONOUS TRANSFER ORBIT (GTO)	8,300 kg 18,300 lbs	22,200 kg 48,940 lbs
PAYLOAD TO MARS	4,020 kg 8,860 lbs	13,600 kg 29,980 lbs



*Performance represents max capability on fully expendable vehicle

Inclination: LEO = 28.5°, GTO = 27°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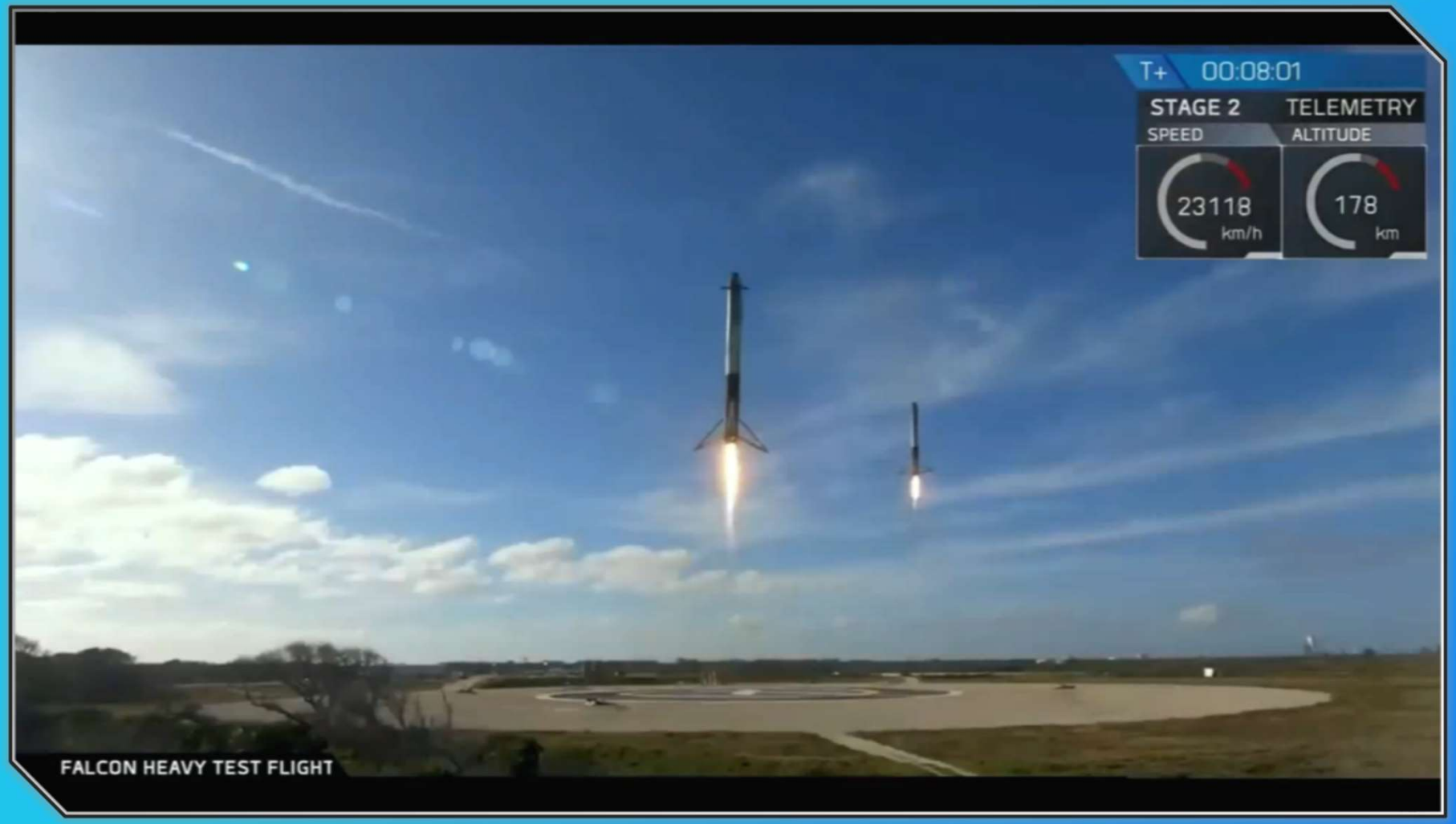
Grid fins steer lift produced by first stage
FAIRING RECOVERY
LAUNCH
VERTICAL LANDING
Engines light one final time bringing first stage to precision landing
VERTICAL LANDING LZ-1
"OF COURSE I STILL LOVE YOU"
Autonomous Spaceport Drone Ship

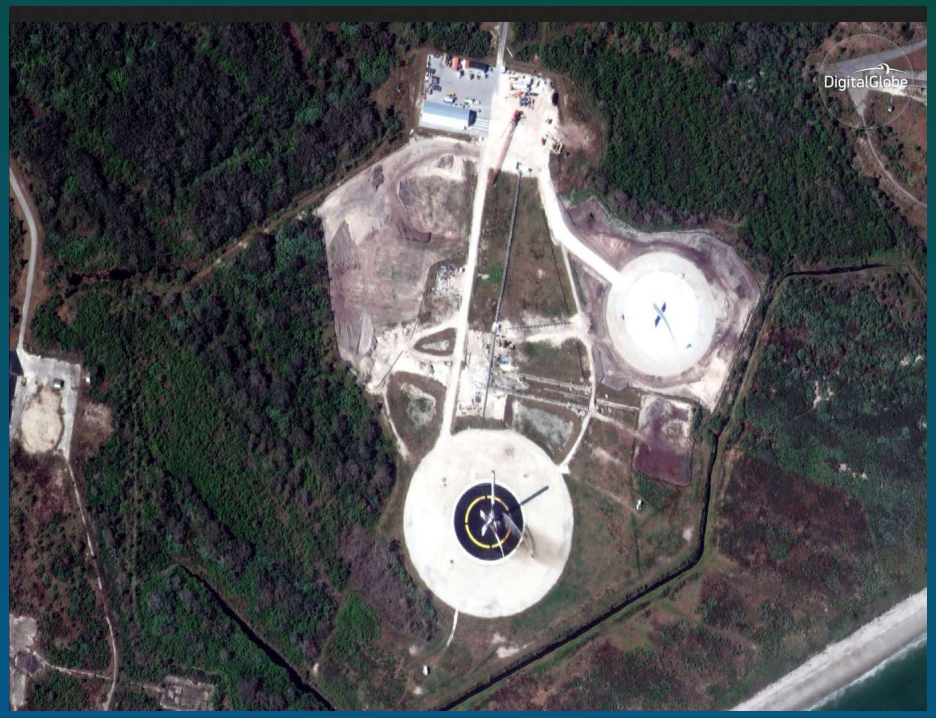
FALCON HEAVY – L'ATTERRAGGIO DEI BOOSTER



LANDING ZONE

LANDING ZONE – LZ1 ED LZ2

Cape Canaveral, Florida (ex complesso di lancio n.° 13)



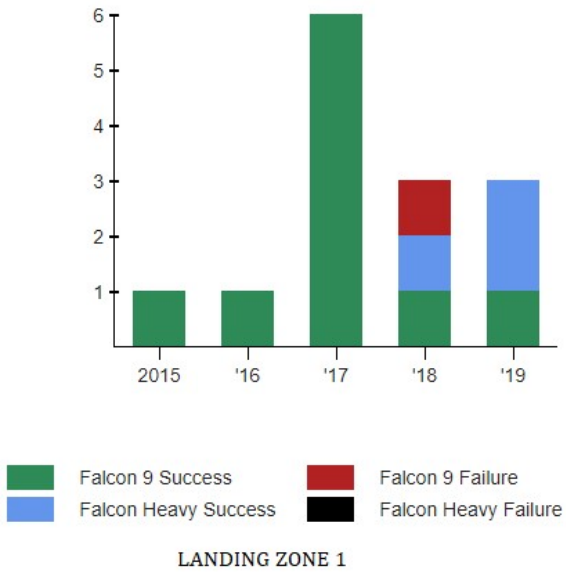
- **DIAMETRO PAD DI ATTERRAGGIO:** 86 m (282 ft)
- Vernice riflettente

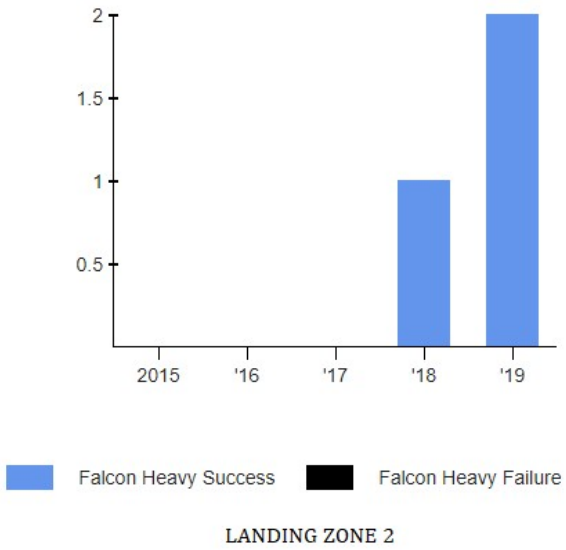
LANDING ZONE – LZ1 ED LZ2

Cape Canaveral, progetto originale

DIAMETRO (PREVISTO) PAD SECONDARI: 46 m (150 ft)

LANDING ZONE – LZ1 ED LZ2





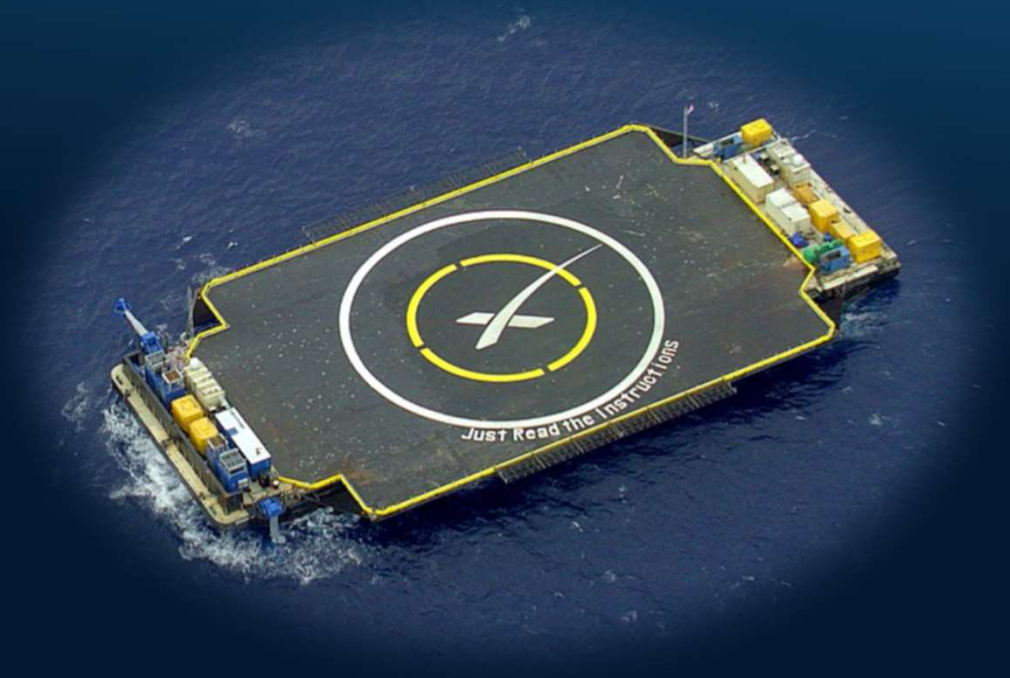
La costruzione della Landing Zone 2 è iniziata nel Maggio 2017

LANDING ZONE – 4W

Vandenberg AF Base, California (SLC 4W)

LANDING ZONE – ASDS

- Oceano Pacifico: *Just Read the Instructions*
- Oceano Atlantico: *Of Course I Still Love You*

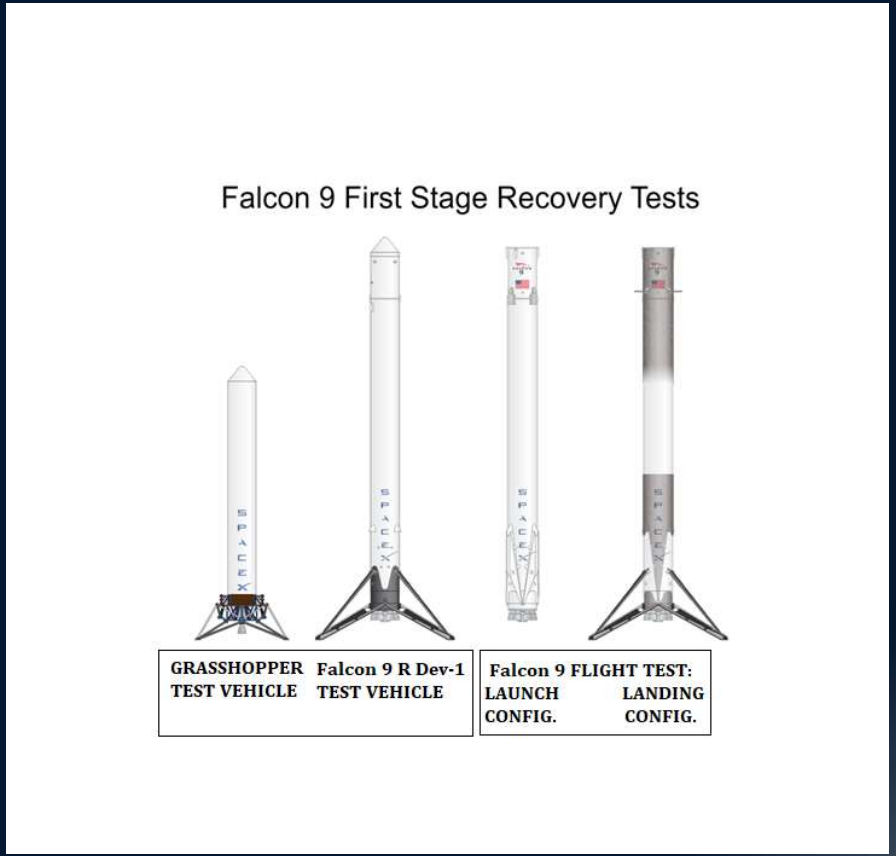


LANDING ZONE – ASDS

- Propulsori azimutali
- Controllo della posizione con GPS (prec. ≈ 3 m, anche con mare mosso)
- È prevista in futuro l'installazione di una stazione di rifornimento per consentire la ripartenza e il rientro sulla terraferma

LA STRADA PER EL DORADO

I VETTORI SPERIMENTALI



I VETTORI SPERIMENTALI - GRASSHOPPER

È un primo stadio del Falcon 9 v1.0

- ALTEZZA: 32 m
- MOTORE: Merlin 1D singolo
- QUOTA MAX: 744 m (7 ottobre 2013)
- CARRELLO D'ATTERRAGGIO: fisso

I VETTORI SPERIMENTALI - GRASSHOPPER

I VETTORI SPERIMENTALI – FALCON 9 R DEV1

È un primo stadio del Falcon 9 v1.1

- ALTEZZA: 50 m
- MOTORE: 3 motori Merlin 1D (il razzo atterrava utilizzando un solo motore)
- QUOTA MAX: 1000 m
- CARRELLO D'ATTERRAGGIO: Mobile

SPACEX: WHAT'S NEXT?

ROCKET LAB

ELECTRON

ROCKET LAB – L'AZIENDA

- Fondata nel 06/2006 (Auckland, Nuova Zelanda) da Peter Beck
- 500 impiegati (2019)
- 2 lanciatori:
  - Ātea
  - Electron
- 2 siti di lancio:
  - LC-1, Mahia
  - Wallops Flight Facility, Virginia

ROCKET LAB – MID-AIR RETRIVIAL

ROCKET LAB – IL LANCIATORE

L'Electron è composto da 4 elementi:

1. **PAYLOAD**
2. **THIRD STAGE (KICK STAGE)**
3. **SECOND STAGE**
4. **FIRST STAGE**

ROCKET LAB – IL LANCIATORE

- **PRIMO VOLO:** 25/05/2017
- **MATERIALE:** Fibra di carbonio
- **ALTEZZA:** 17 m
- **DIAMETRO:** 1.2 m
- **MASSA:** 12500 kg
- **PAYLOAD:** 150-225 kg

ROCKET LAB – IL LANCIATORE

- **MOTORE PRIMO STADIO:** Rutherford (x9), 192 kN tot., ISP = 303 s
- **MOTORE SECONDO STADIO:** Rutherford ottimizzato per il vuoto (x1), 22 kN, ISP = 333 S
- **MOTORE KICK STAGE:** Curie (x1), 120 N

- Propellente:
  - Rutherford: ossigeno liquido/RP-1
  - Curie: liquido
- Il motore Rutherford è alimentato da una pompa elettrica
- I componenti del motore sono quasi tutti realizzati con la tecnologia della stampa 3D (circa 24h per la realizzazione)

I PROBLEMI TECNICI DEL RIENTRO

DEFINIZIONE DI RIENTRO ATMOSFERICO: fase di attraversamento dell'atmosfera di un veicolo che ritorna sulla Terra da una missione nello spazio

I requisiti di una missione di rientro sono dettati dalle seguenti problematiche:

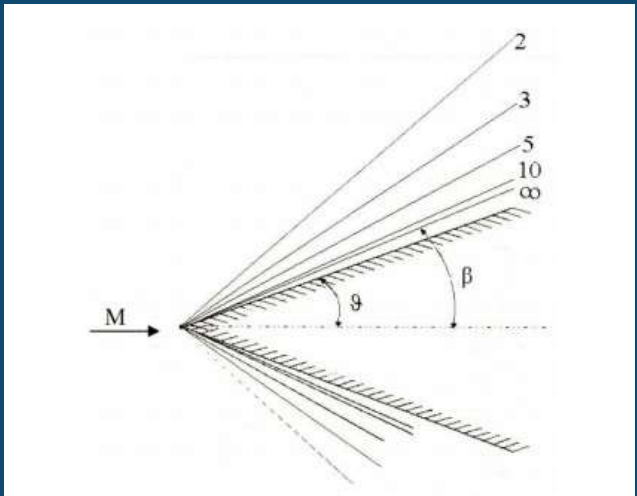
1. FORTI DECELERAZIONI
2. INTENSO SCAMBIO DI CALORE
3. PRECISIONE NELL'ATTERRAGGIO

I PROBLEMI TECNICI DEL RIENTRO

REGIMI DI MOTO RAREFATTI (basse densità) ⟶ $Kn = \frac{\lambda}{L} > 0.2$

REGIMI DI MOTO IPERSONICI ⟶ Limite convenzionale Mach = 5

- Profili aguzzi: onde d'urto molto prossime al corpo



- Profili tozzi: flusso termico ridotto sulla superficie del veicolo

GRAZIE PER L'ASCOLTO!

Un ringraziamento e un saluto all'Ingegner G. Savarese