Space Informatics

Week 10: Safety and Reliability of Space System

Computer Science and Communications, University of Luxembourg

19 November 2019

Part 2

safety and reliability

objectives of the future lectures:

consider cyber-physical systems at a higher level

safety and reliability

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→ less code, more abstracted complex systems

safety and reliability

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consider cyber-physical systems at a higher level

→ less code, more abstracted complex systems

→ human reasoning

safety and reliability

overview of the future lectures (“to be presented” techniques):

→ for safety:

anticipate a dreaded event by identifying relations between causes and consequences

safety and reliability

overview of the future lectures (“to be presented” techniques):

→ for safety:

anticipate a dreaded event by identifying relations between causes and consequences

→ for reliability:

prove that pieces of code are correct

prove that a complex cyber physical system (e.g. a Cubesat) behaves as expected

safety

1. fault tree analysis, a powerful technique
2. fault trees 101
3. examples of gates and events
4. Fault tree analysis: a concrete case study
5. Fault trees events: unintended or maliciously provoked
6. Fault tree analysis: what is next?

fault tree analysis in a nutshell

- model cyber physical systems failure scenario

fault tree analysis in a nutshell

- model cyber physical systems failure scenario
- evaluate risks in order to find countermeasures

fault tree analysis

- H. A. Watson at Bell Telephone Laboratories (1961)
- at first, used by the U.S. Air Force
- shortly after, adopted by Boeing for their commercial flights
- Further developed and extended

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Safety norms for
space systems,
ISO 26262
ISO 14620-1

fault tree analysis

- deductive method using *human reasoning*

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- guess/determine direct causes of the event (events of level 1)

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- events can be combined together as necessary and sufficient conditions for the consequence to happen.

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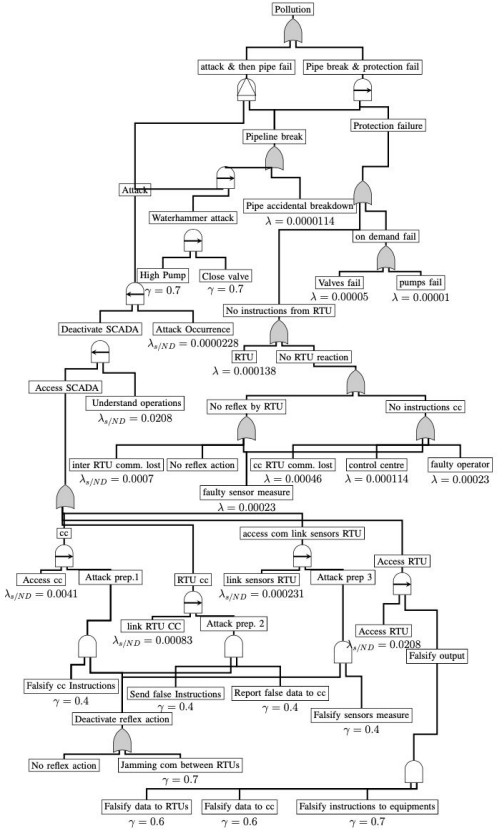
- such that each cause (event) of level 1 is a consequence of causes (events) of level 2
- events can be combined together as necessary and sufficient conditions for the consequence to happen.
- … “unfold” causes and consequences until events at level XX are no longer decomposable (leaf)

fault tree analysis



looks like an inverted tree

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Fault trees structure

Simple structure; two types of elements

- **Logical gates**

The output of a logical gate at level N is a consequence of a combination of events of level N+1

Fault trees structure

Simple structure; two types of elements

- **Logical gates**

The output of a logical gate at level N is a consequence of a combination of events of level N+1

A gate is referred as a *parent*, while its input events are referred as its *children*

- indecomposable events: **leaves**

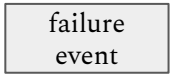
Leaves can be found at each level, however leaves have **no children.**

Logical gates

- combine different events together (input children)
- model goals, objectives (parents): *outputs whether the goal is achieved or not*

- AND gate: 
- OR gate: 
- SAND gate (sequential AND): 
- PAND gate (parallel AND): 
- ….

Failure events

- leaves of the tree (children) 

- indecomposable into smaller events: usually an expert opinion

- a timed system, a probabilistic system, a discrete system…
- a simple electrical component
- a basic human action

→ possibly eventually fails: its output becomes an input of its parent gate.

Examples of failure events

- Pressure control system failure: sensor disconnected; can we recover? Do we have sensors still working?

- Switch out of service: flawed component, fatality

- Communication system not responding: poor connectivity? possibility to recover?

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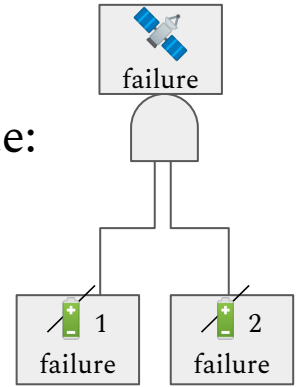
Gate: AND 1

AND gate:

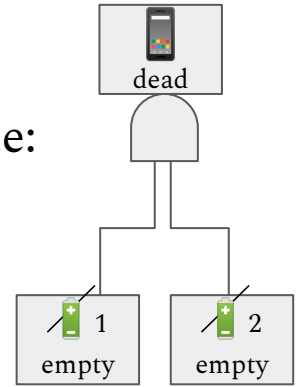


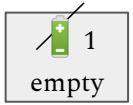
if 1 failure **and** 2 failure occur, then the gate is activated and the failure occurs (the objective).

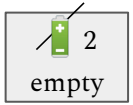
Battery failure: probability?

Gate: AND 2

AND gate:



if 

and 

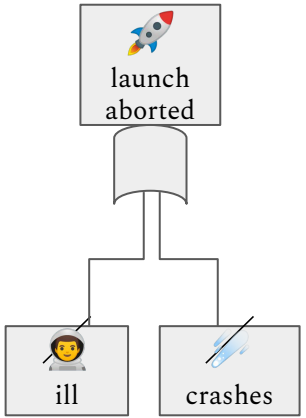
occur, then the gate is activated and 

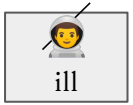
occurs.

Battery empty: mathematical equation to model the power consumption?

Gate: OR 1

OR gate:

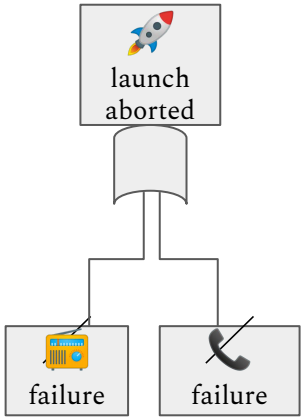


if  **or**  then the gate is activated and the 

Events: combination of probabilities and mathematical models?

Gate: OR 2

OR gate:



if failure **or** failure then the gate is activated and the launch aborted

Lost connection: issues with the component manufacturer?

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overview of the mission

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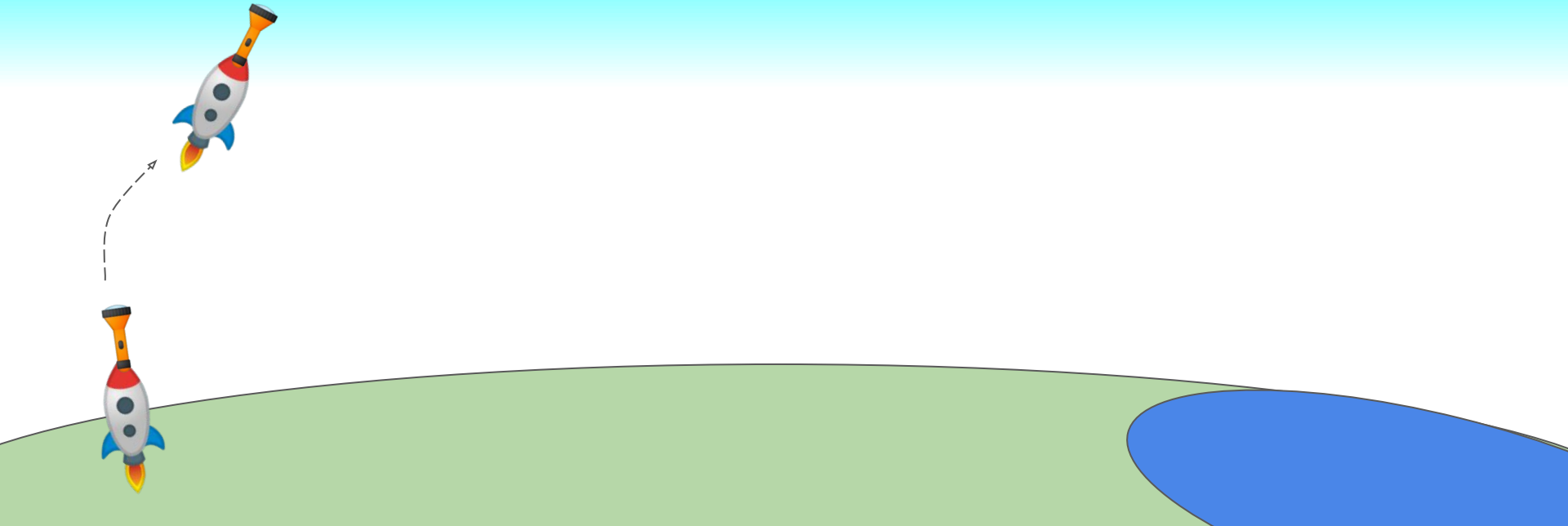
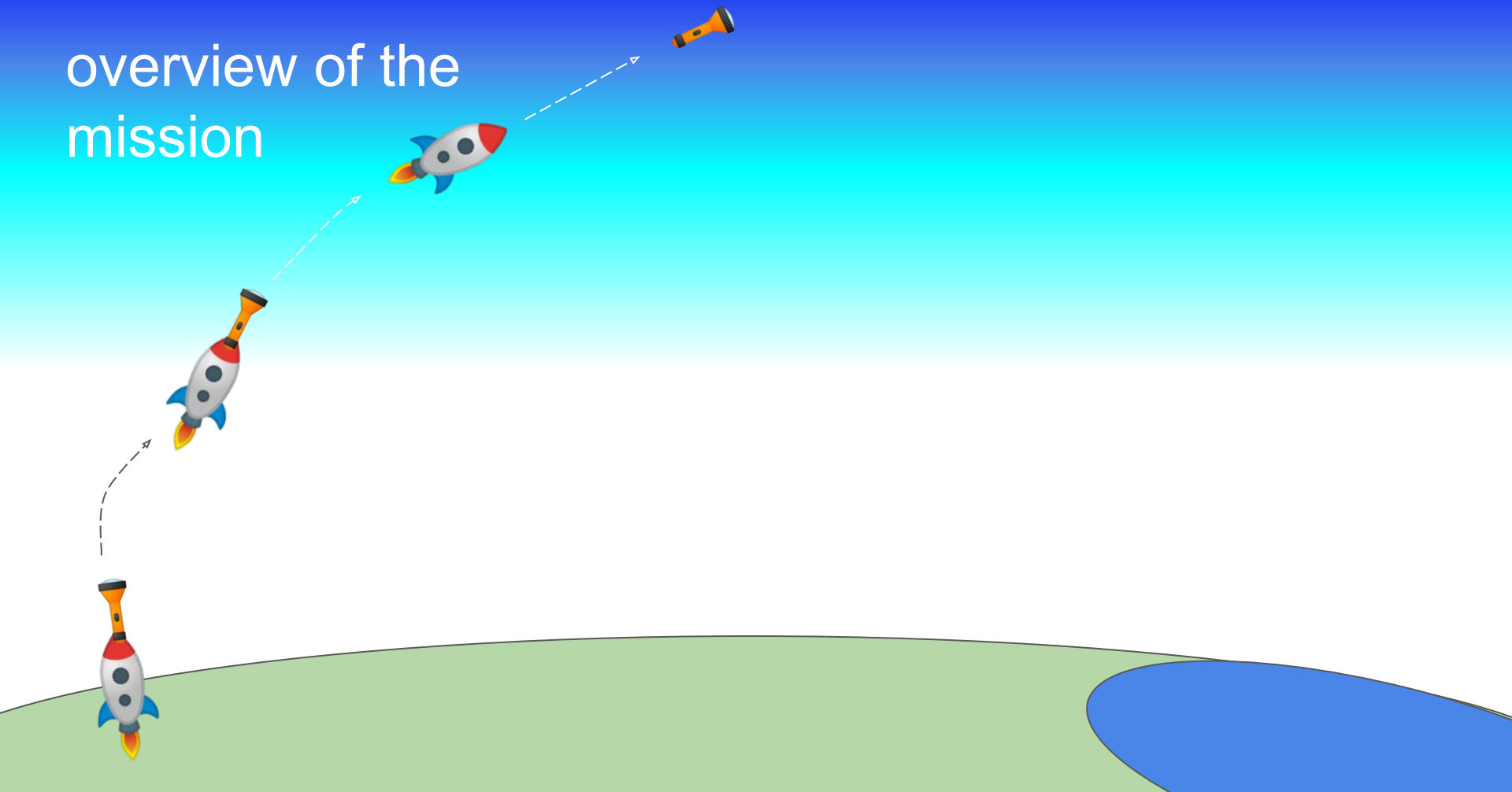


overview of the mission



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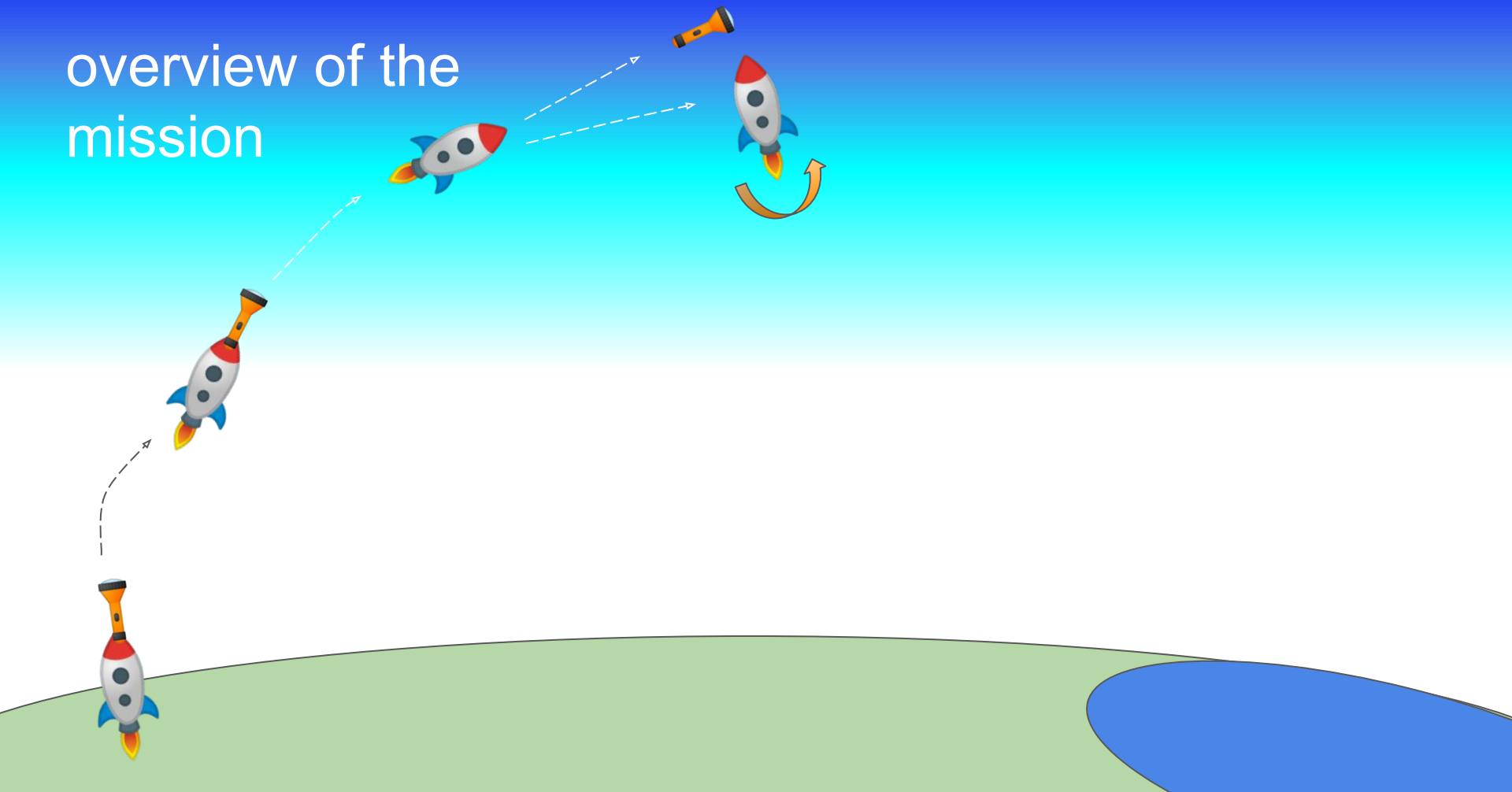

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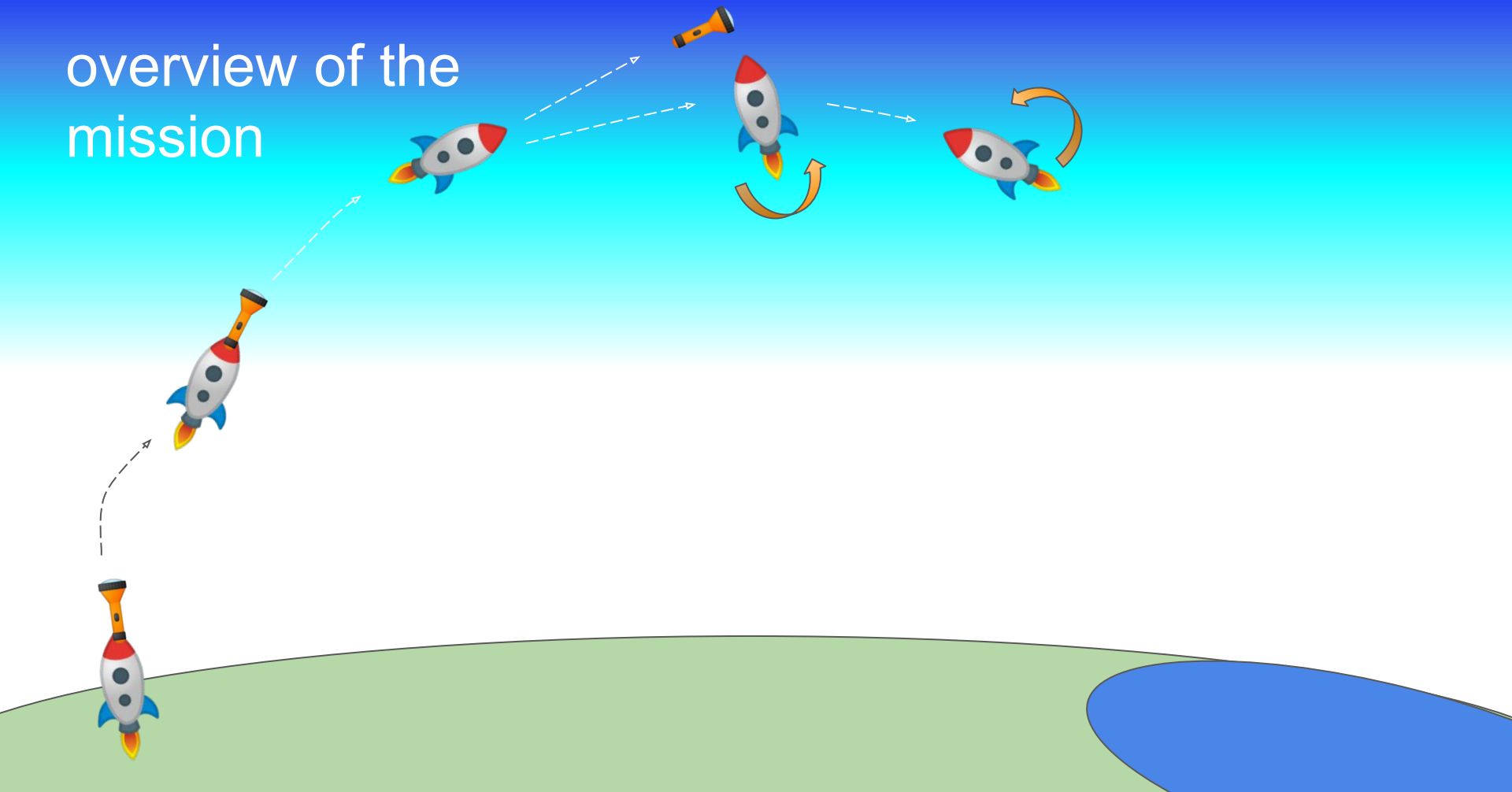

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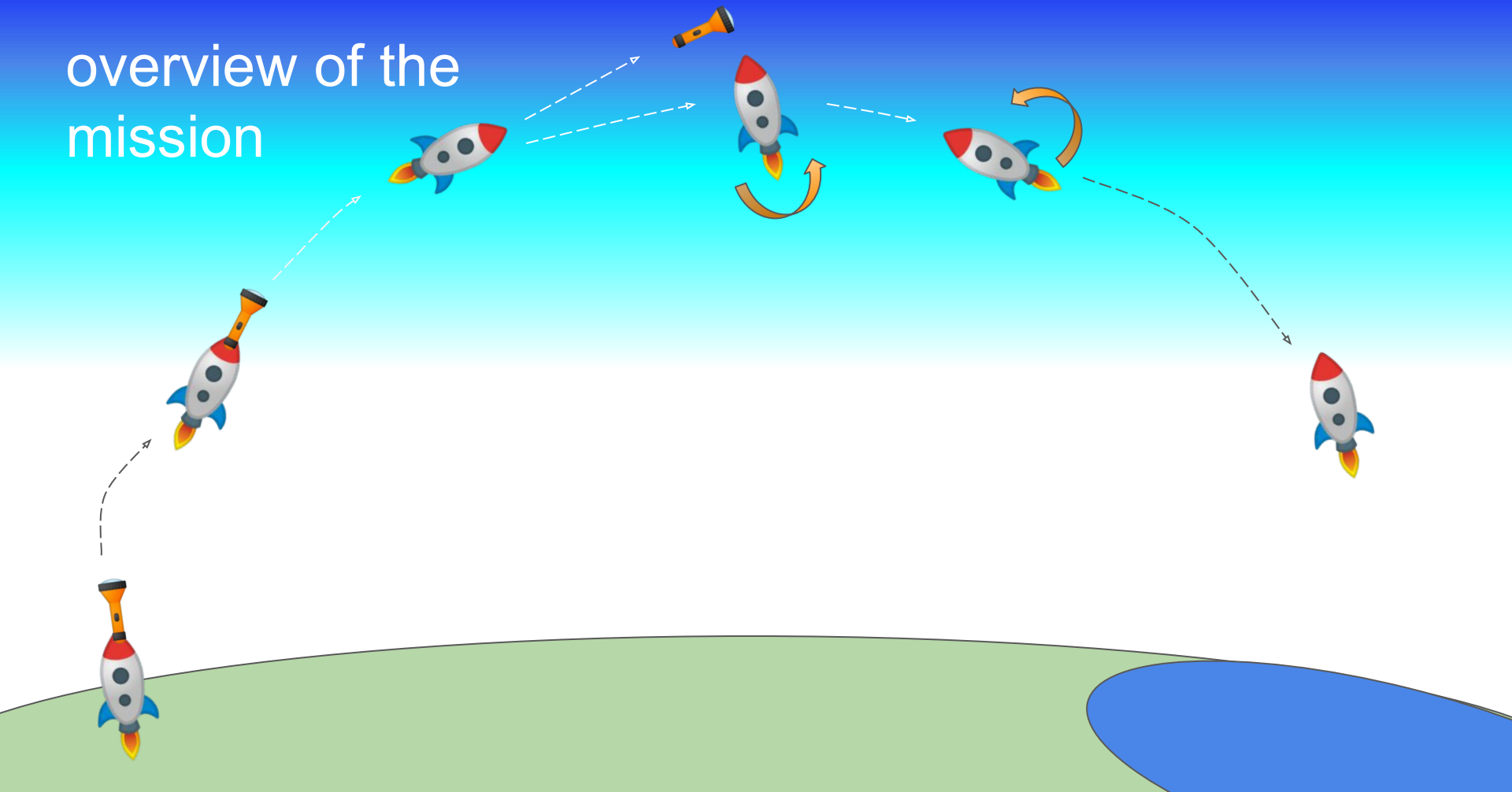

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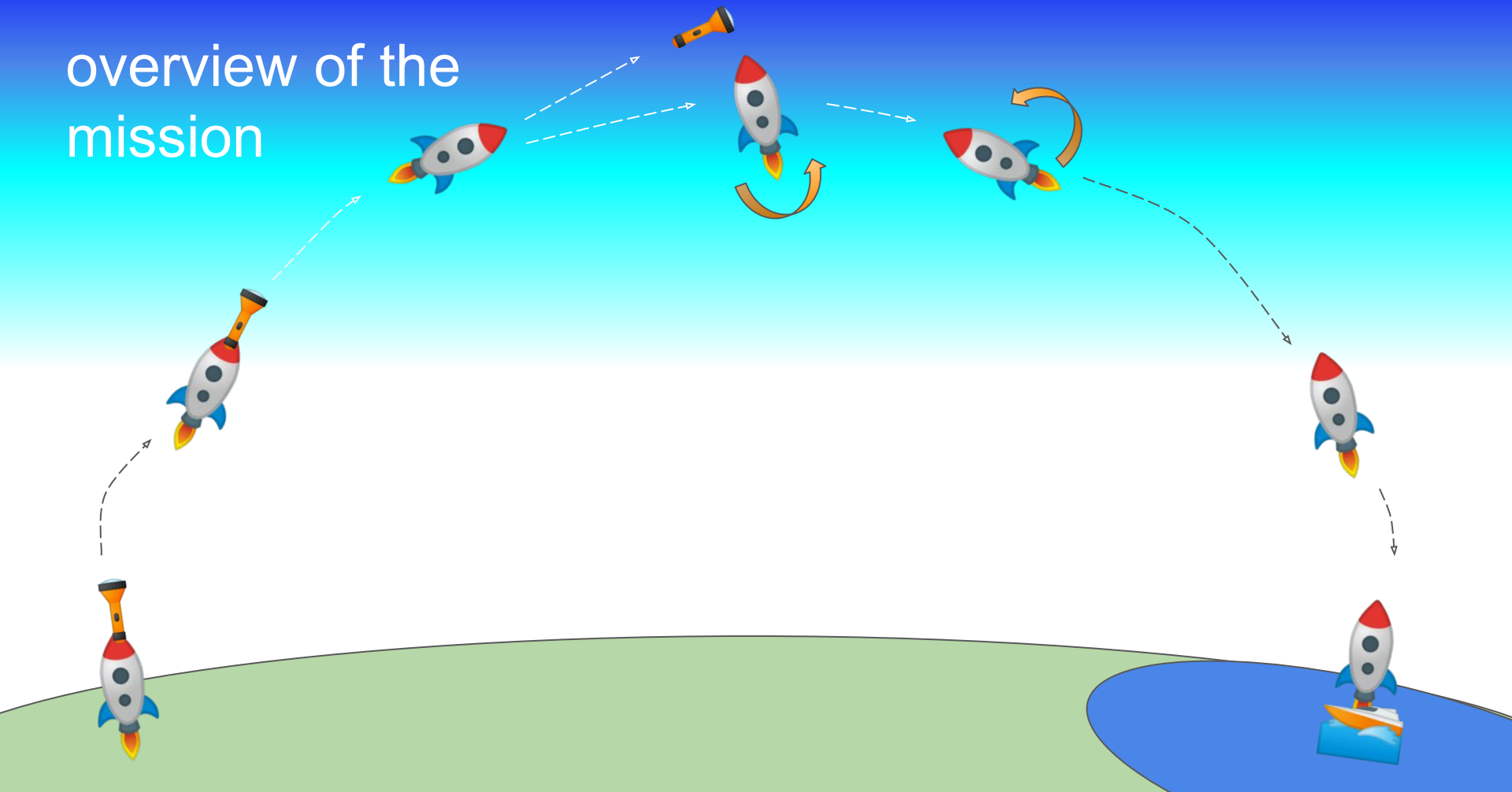
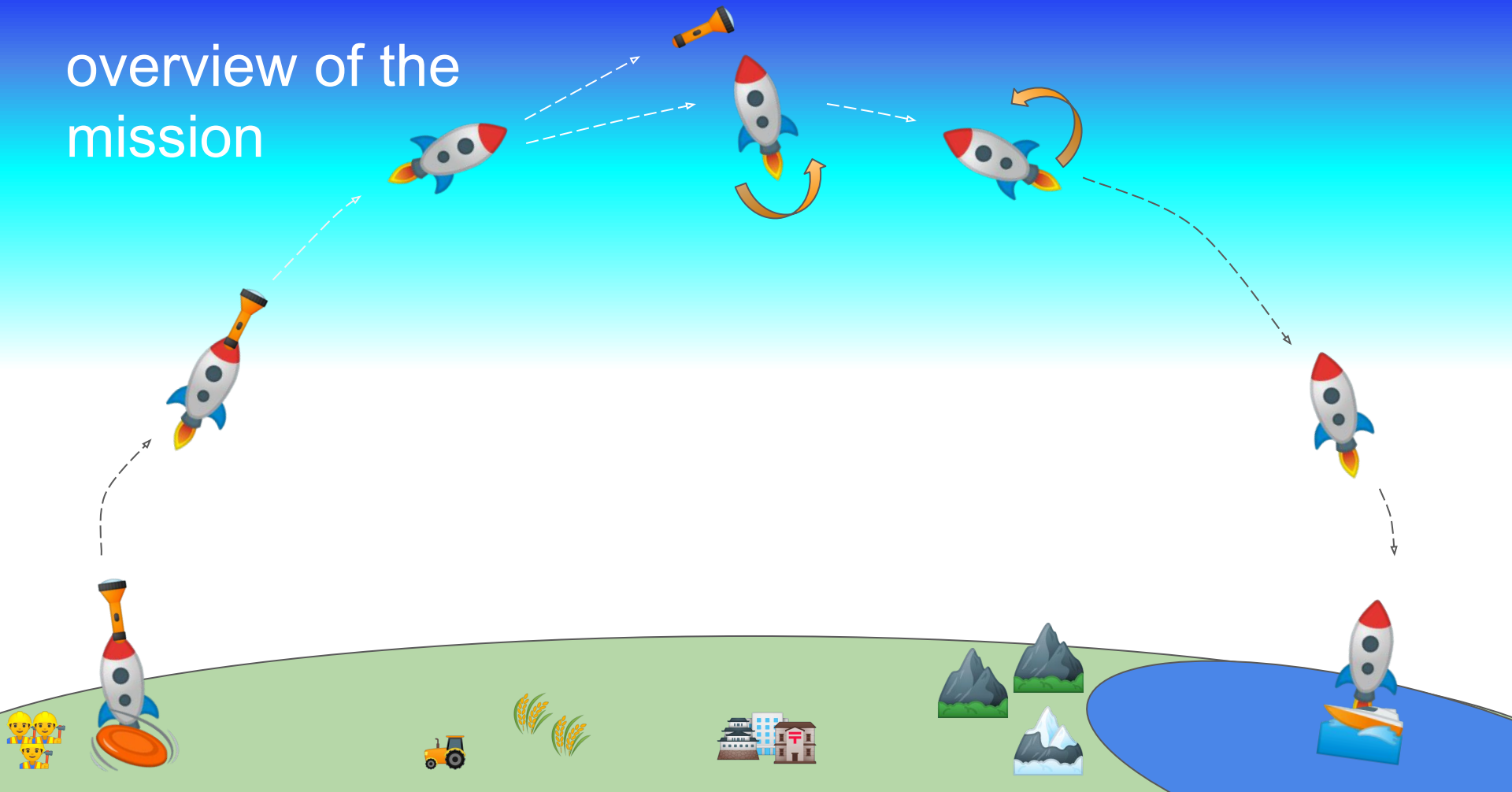


General objectives

- Critical: no human damages 💀
- High: no property destroyed on the ground 💰
- Medium: fail to put the payload in Low Earth Orbit (LEO)

overview of the mission



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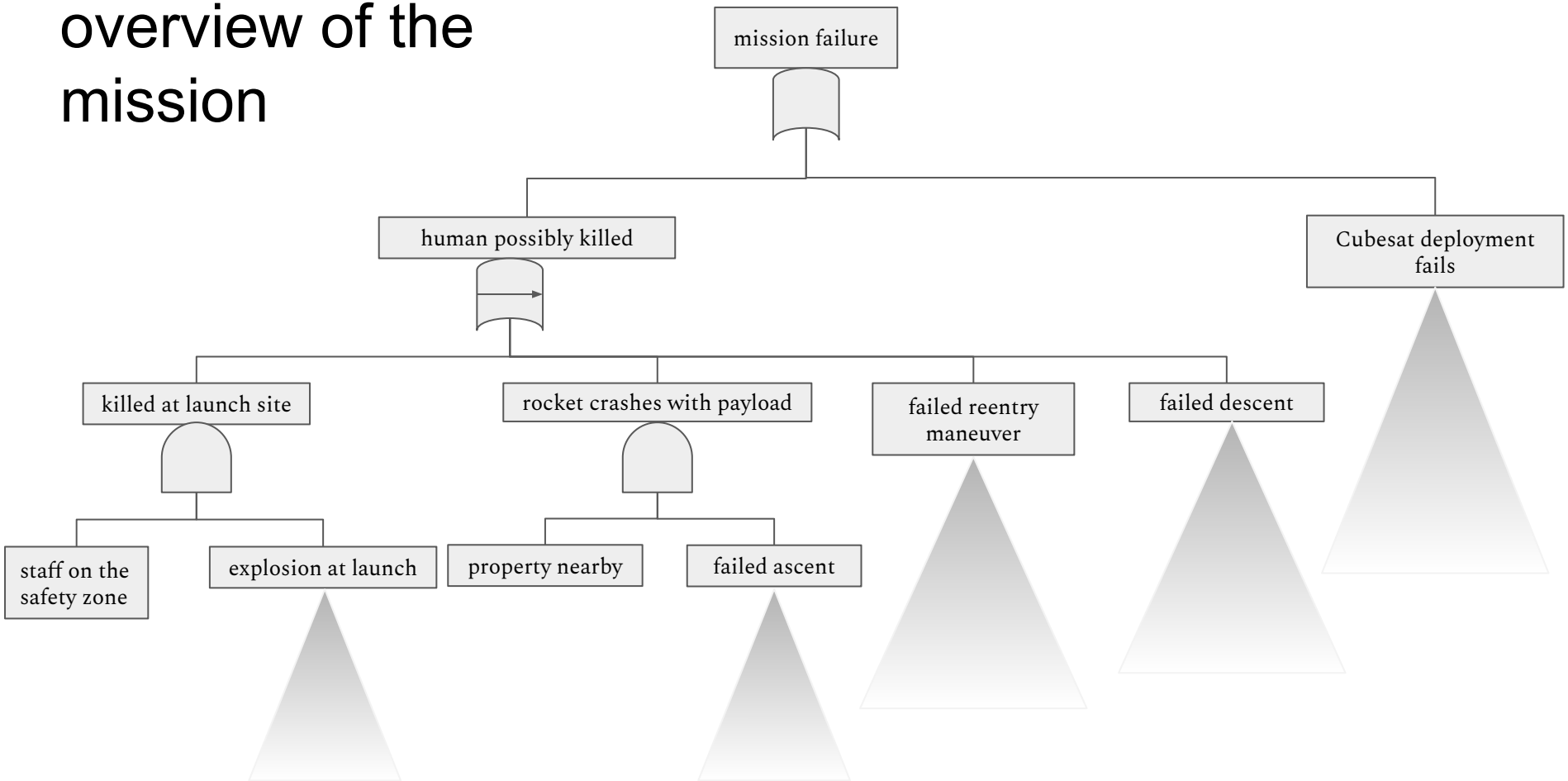
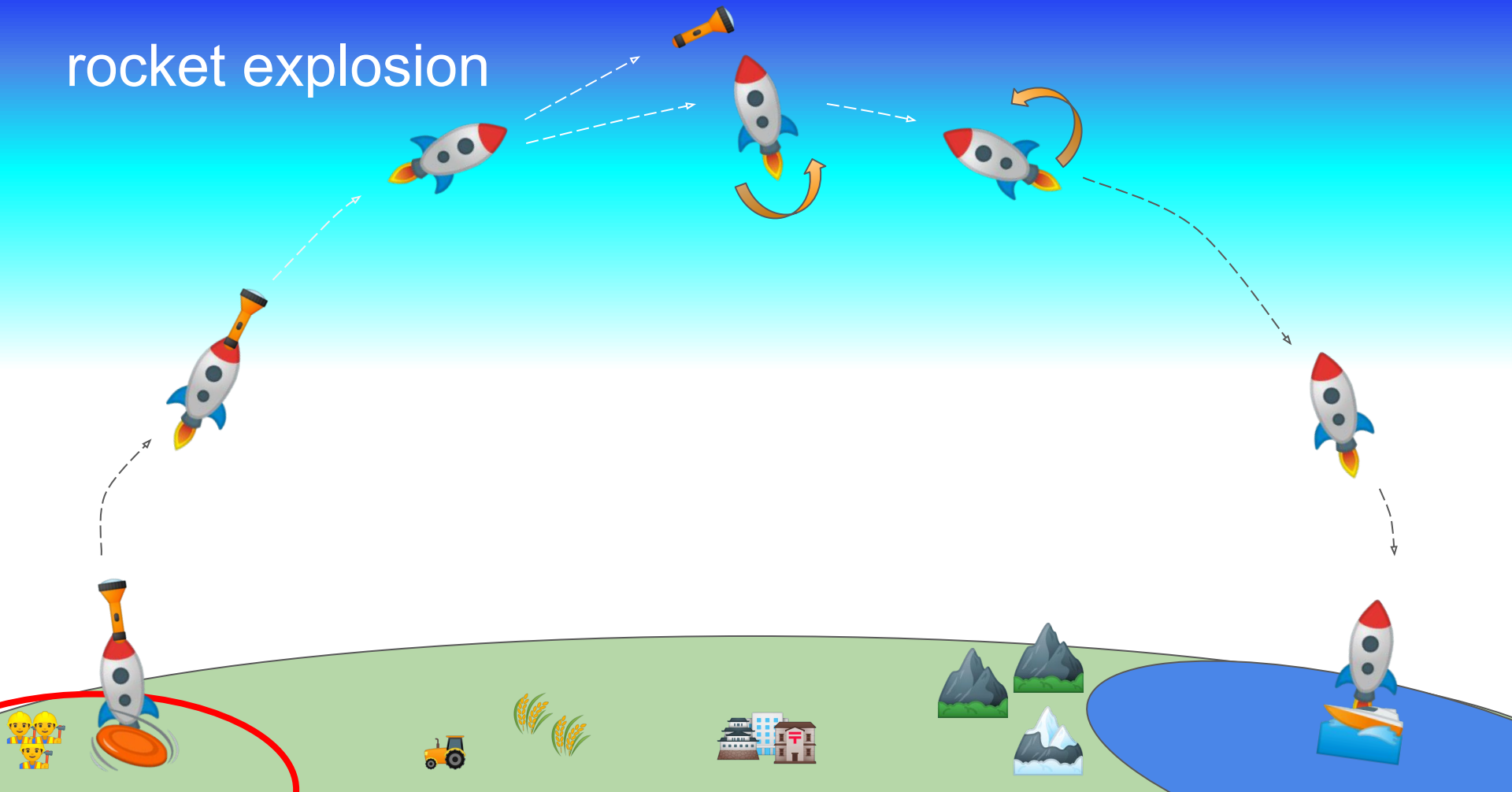


rocket explosion

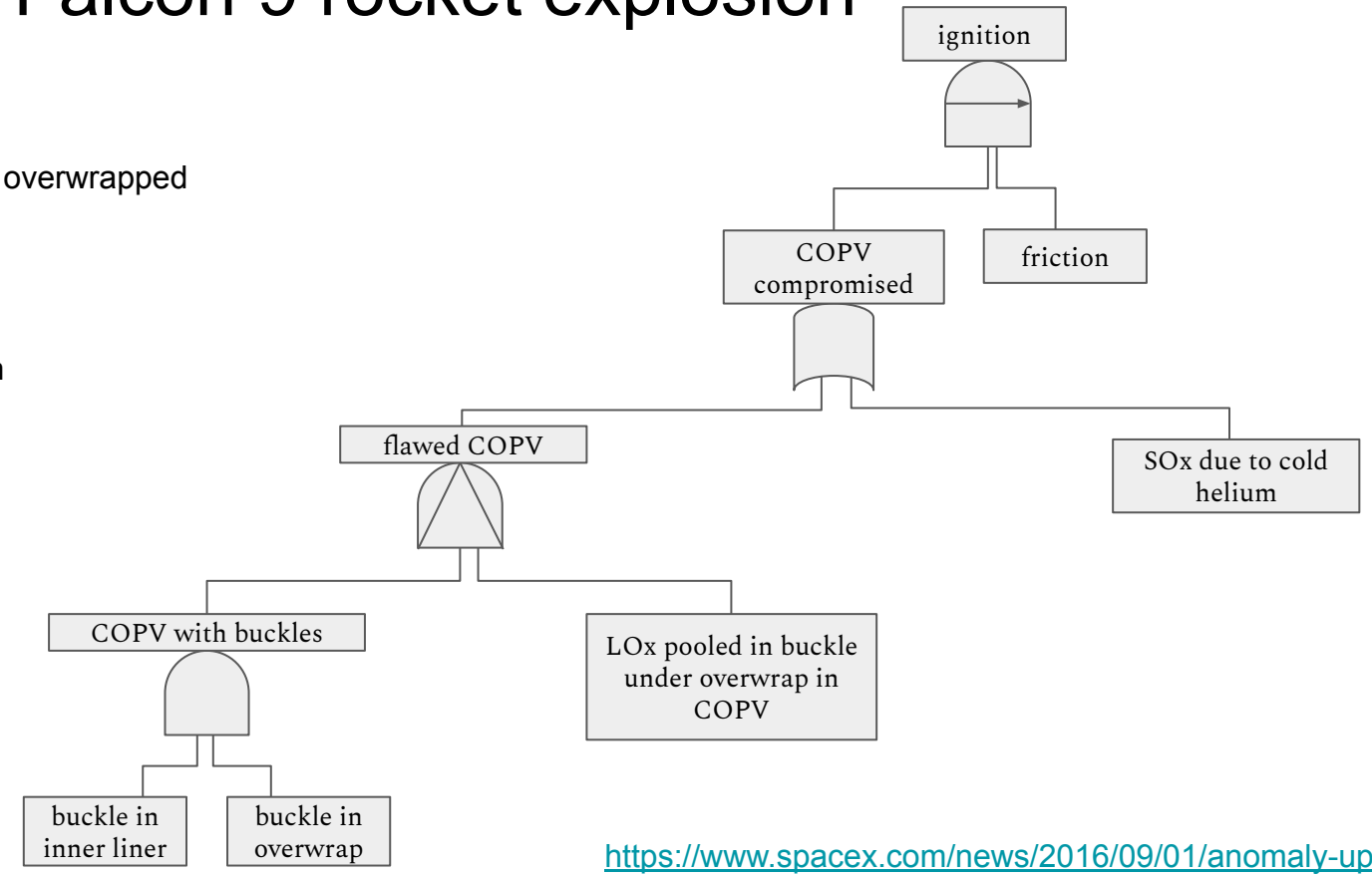


SpaceX Falcon 9 rocket explosion

COPV: composite overwrapped pressure vessel

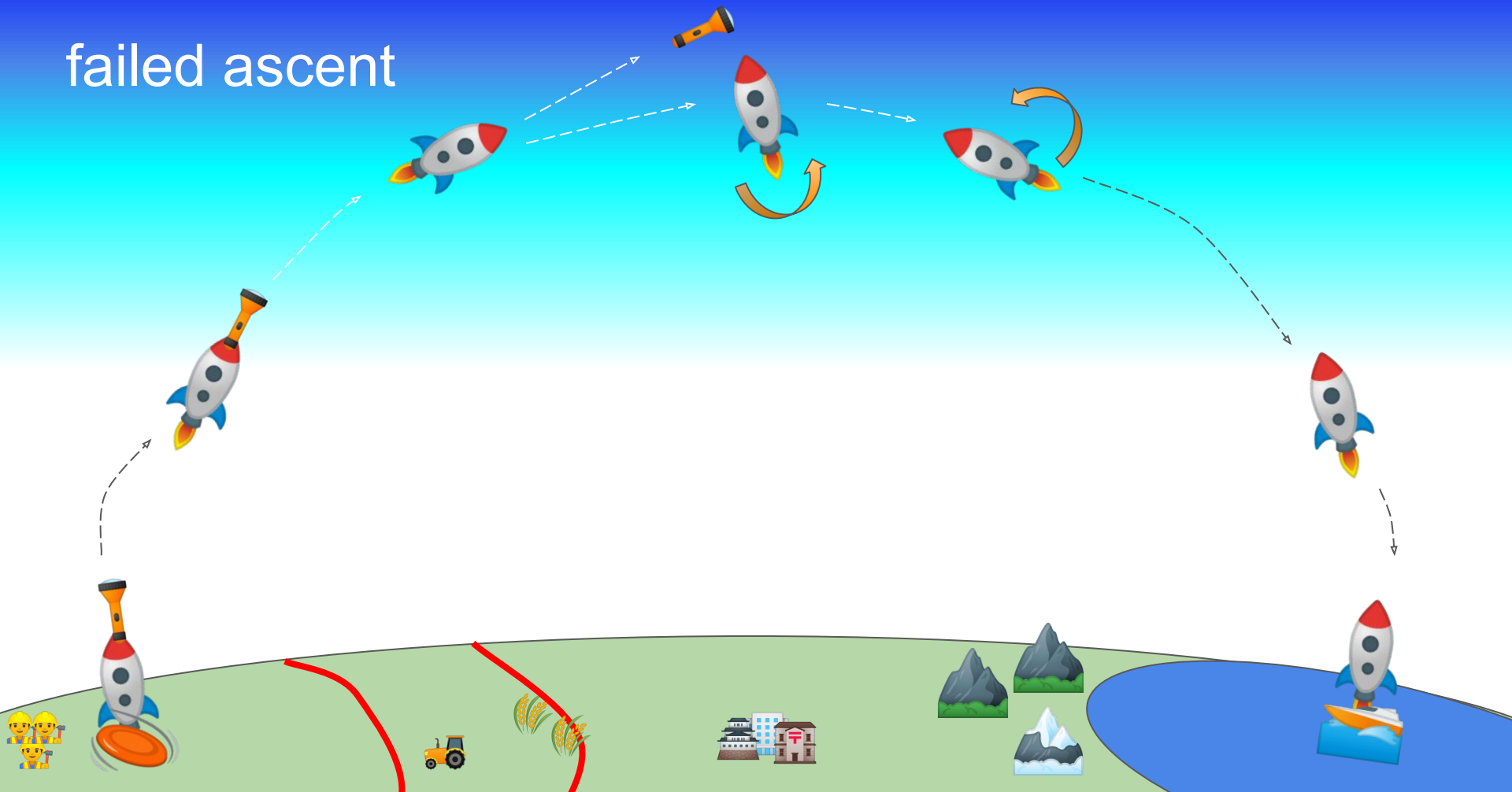
SOx: solid oxygen

LOx: liquid oxygen

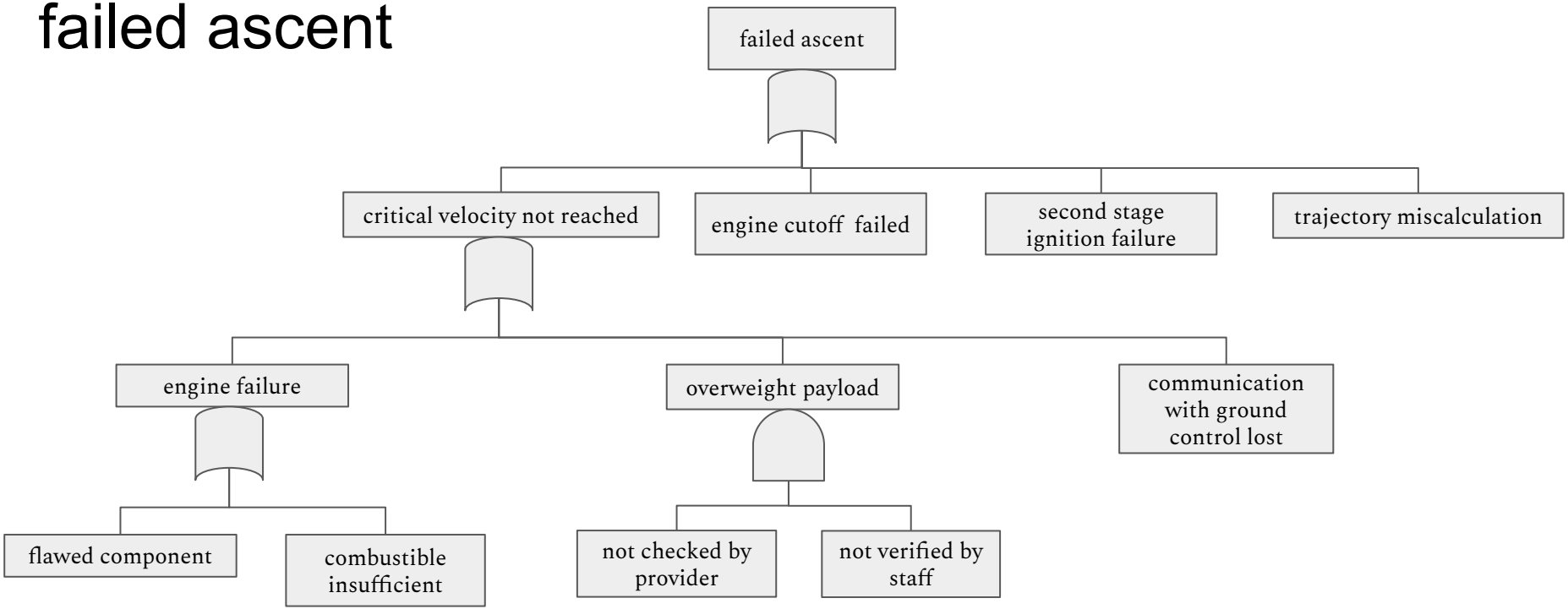


https://www.spacex.com/news/2016/09/01/anomaly-updates

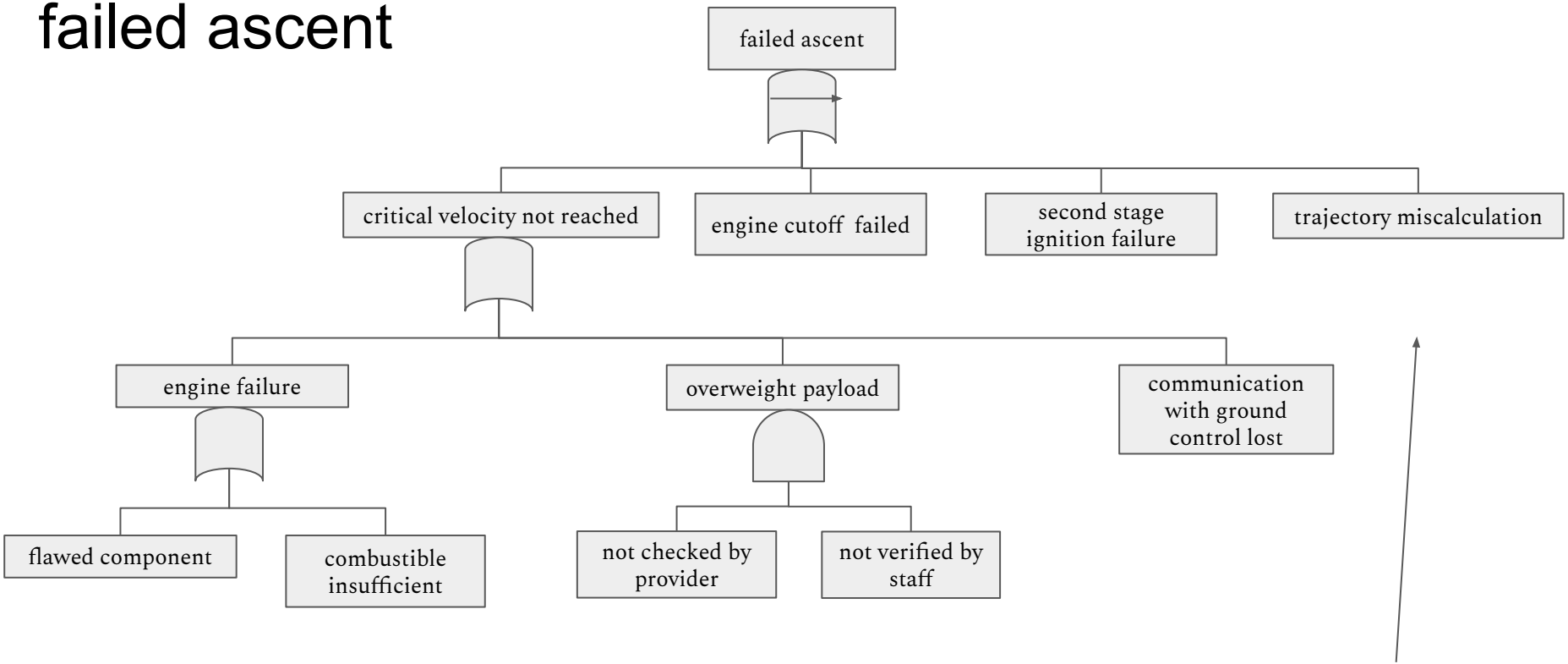
failed ascent



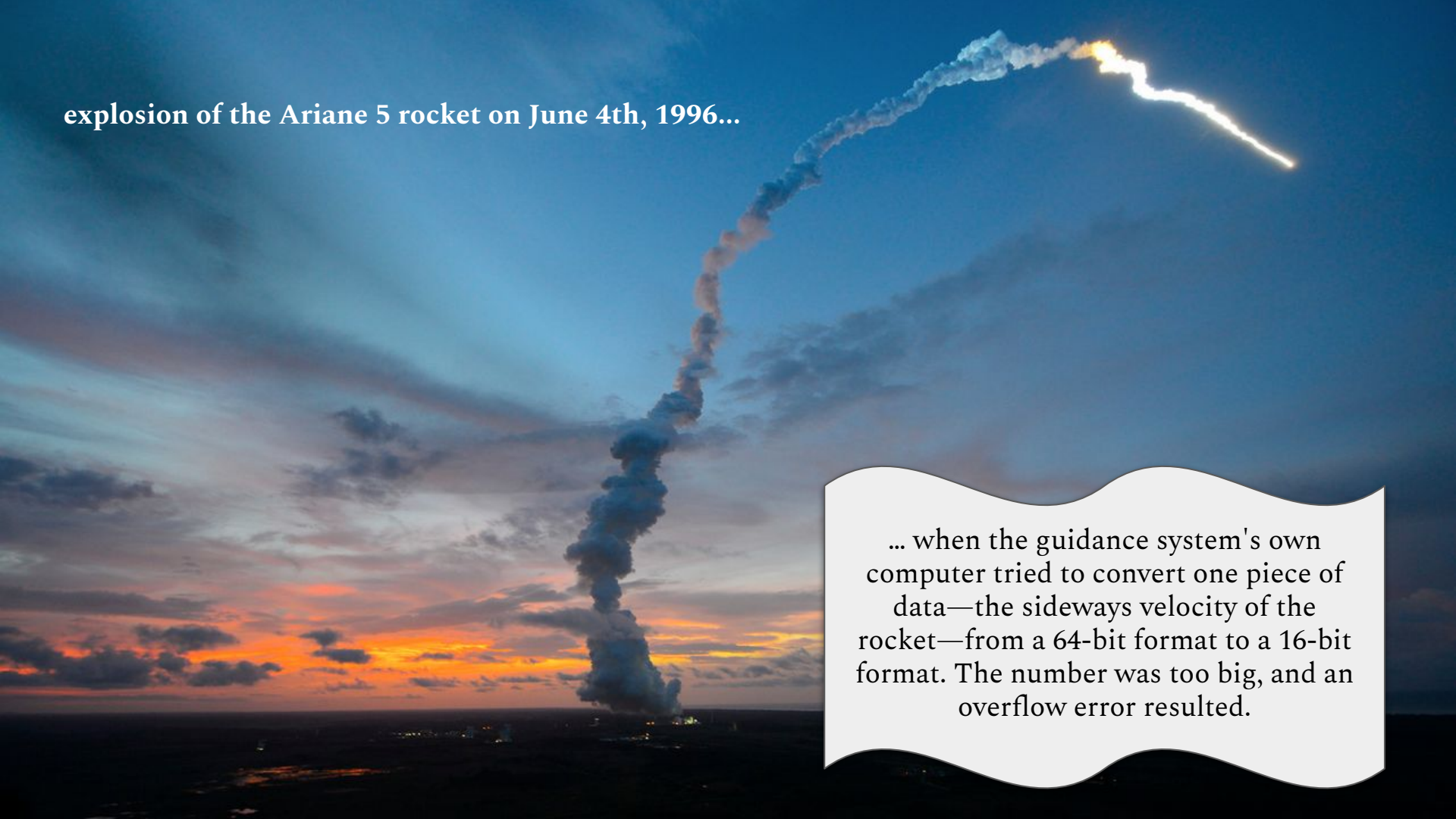
failed ascent



failed ascent



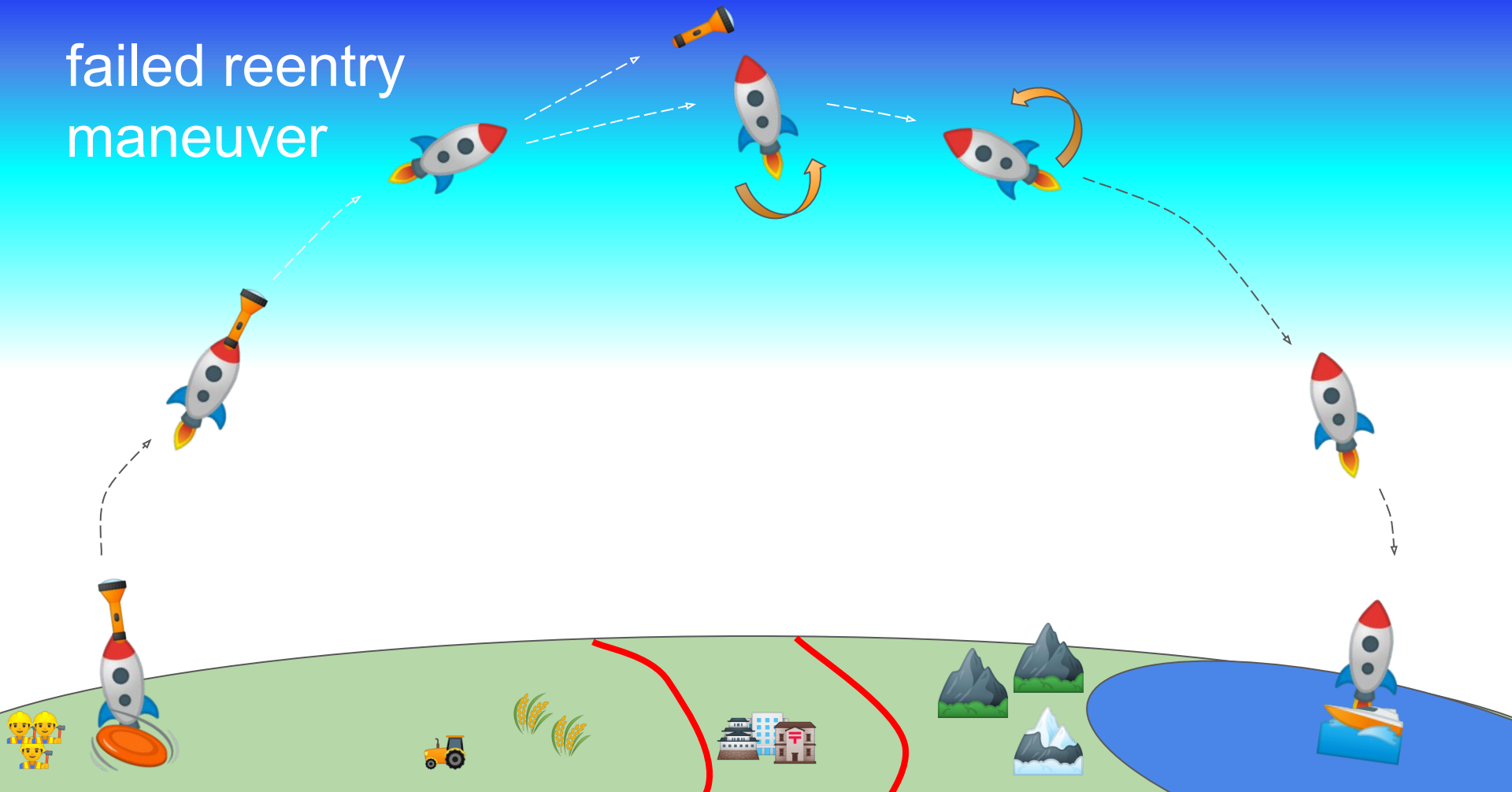
E.g., Ariane 5 failed due to a software vulnerability.



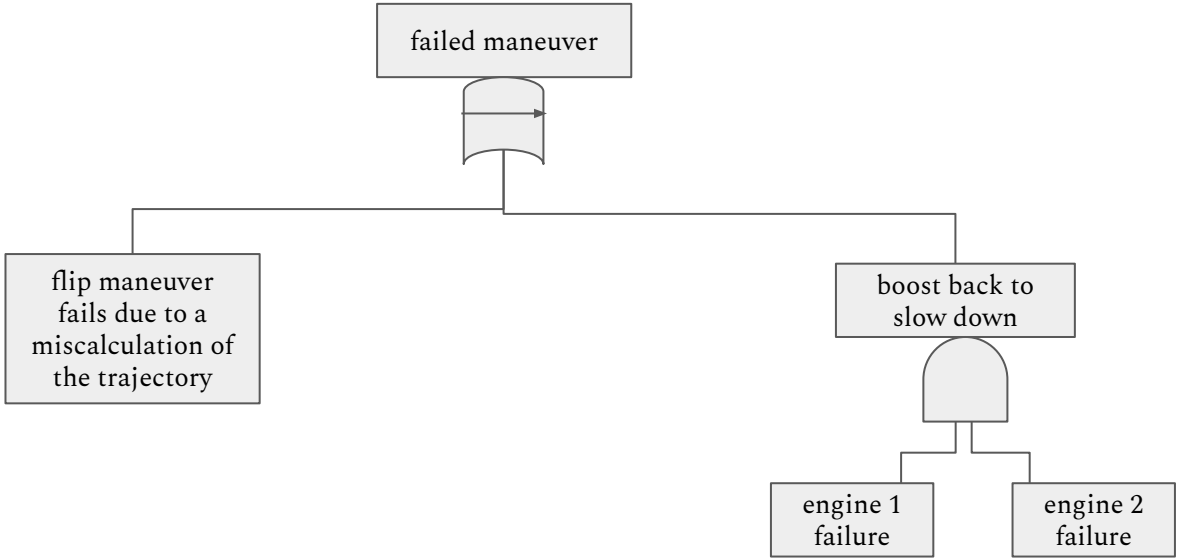
explosion of the Ariane 5 rocket on June 4th, 1996...

... when the guidance system's own computer tried to convert one piece of data—the sideways velocity of the rocket—from a 64-bit format to a 16-bit format. The number was too big, and an overflow error resulted.

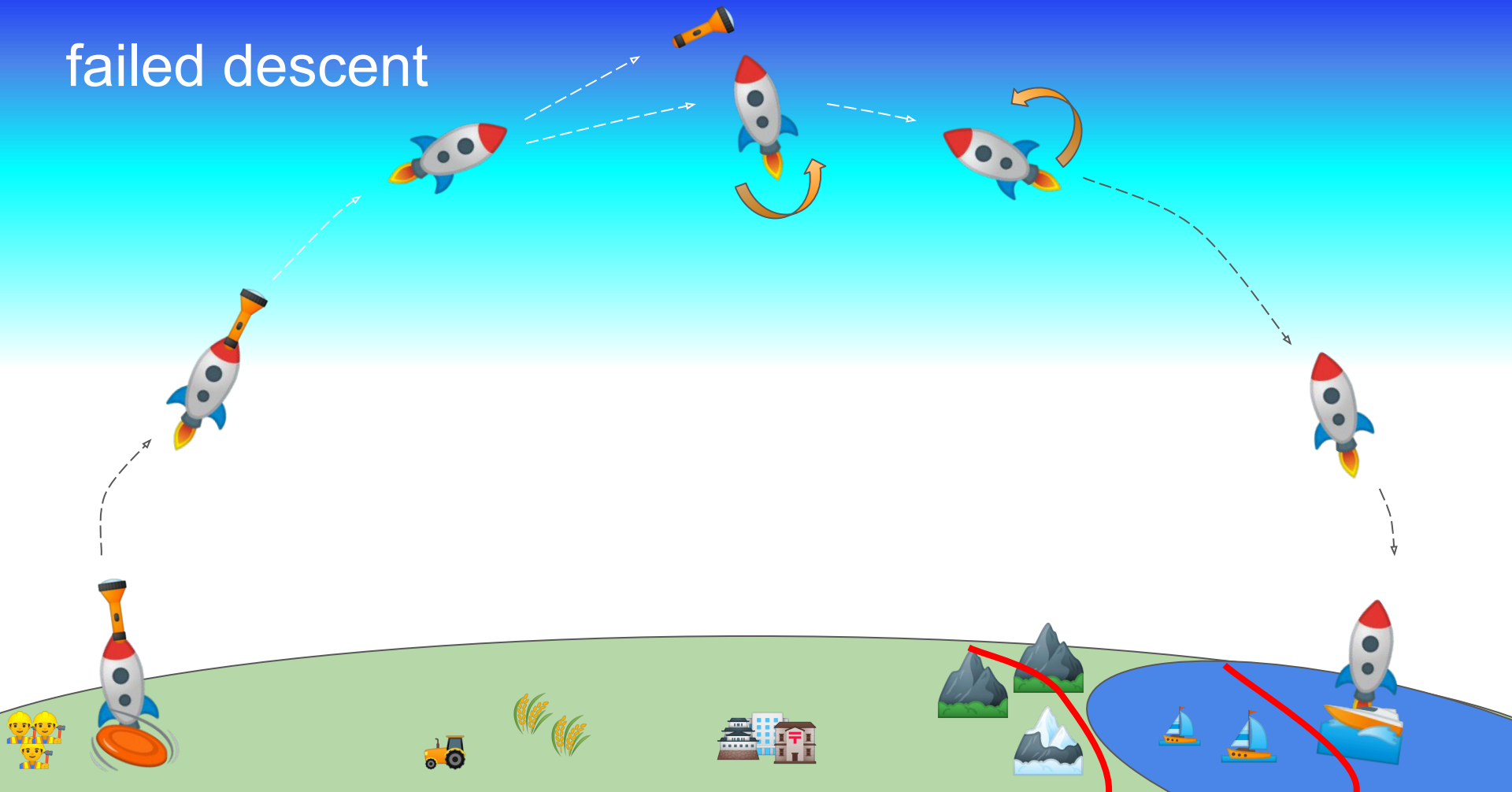
failed reentry maneuver



failed reentry maneuver



failed descent



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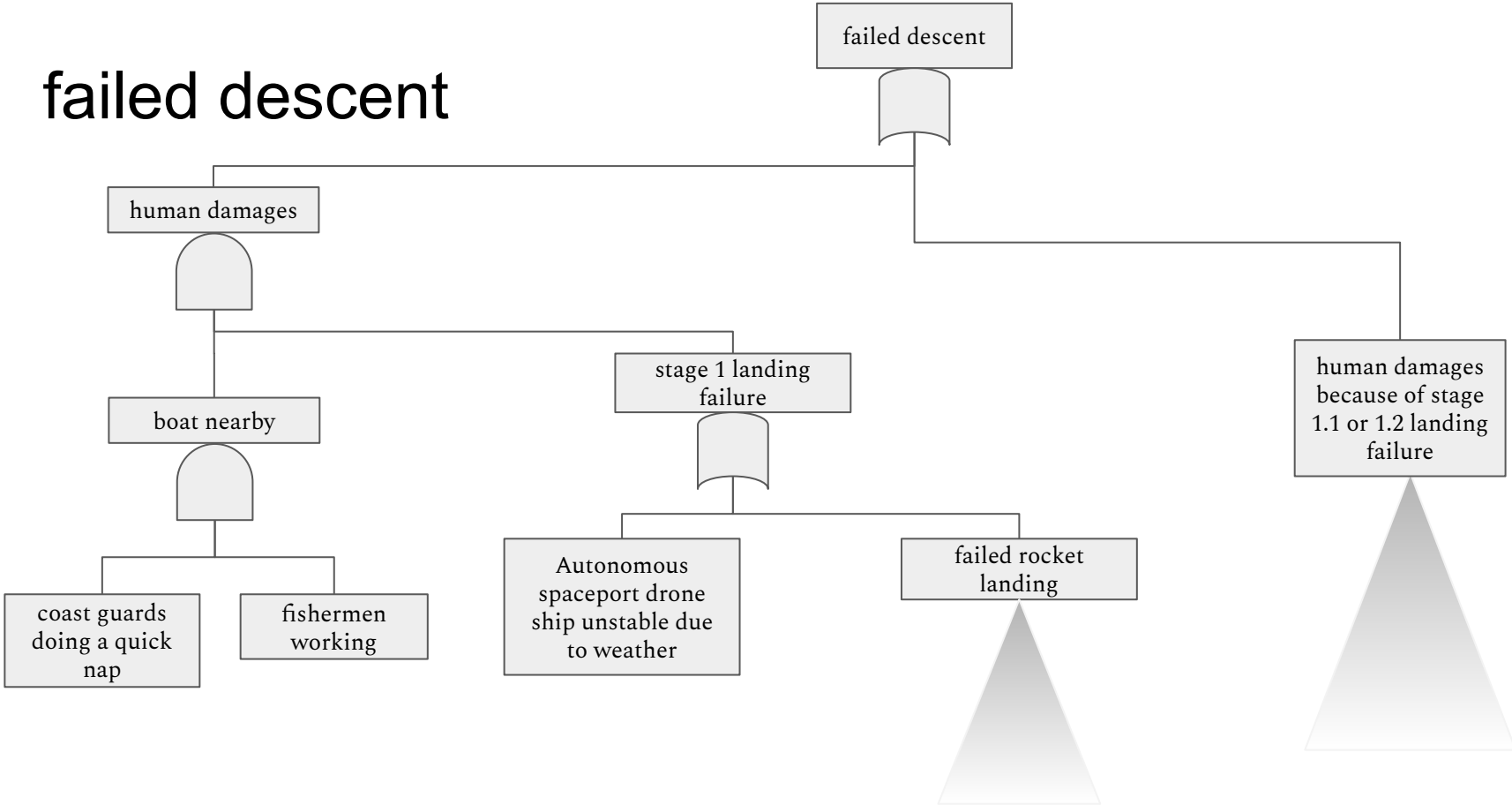
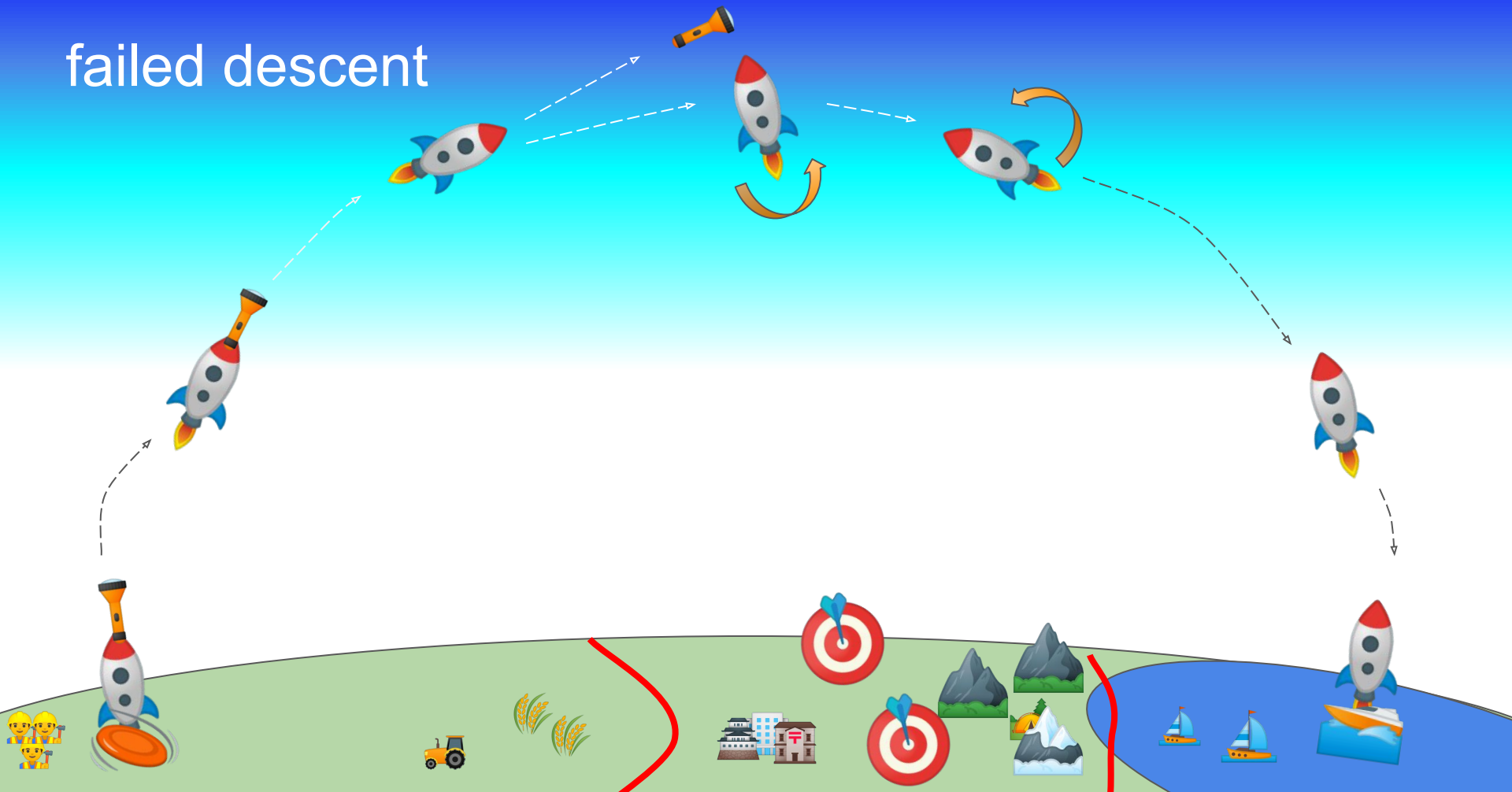


Reassembling sub-trees

Provides flexibility in the design process of fault-trees.

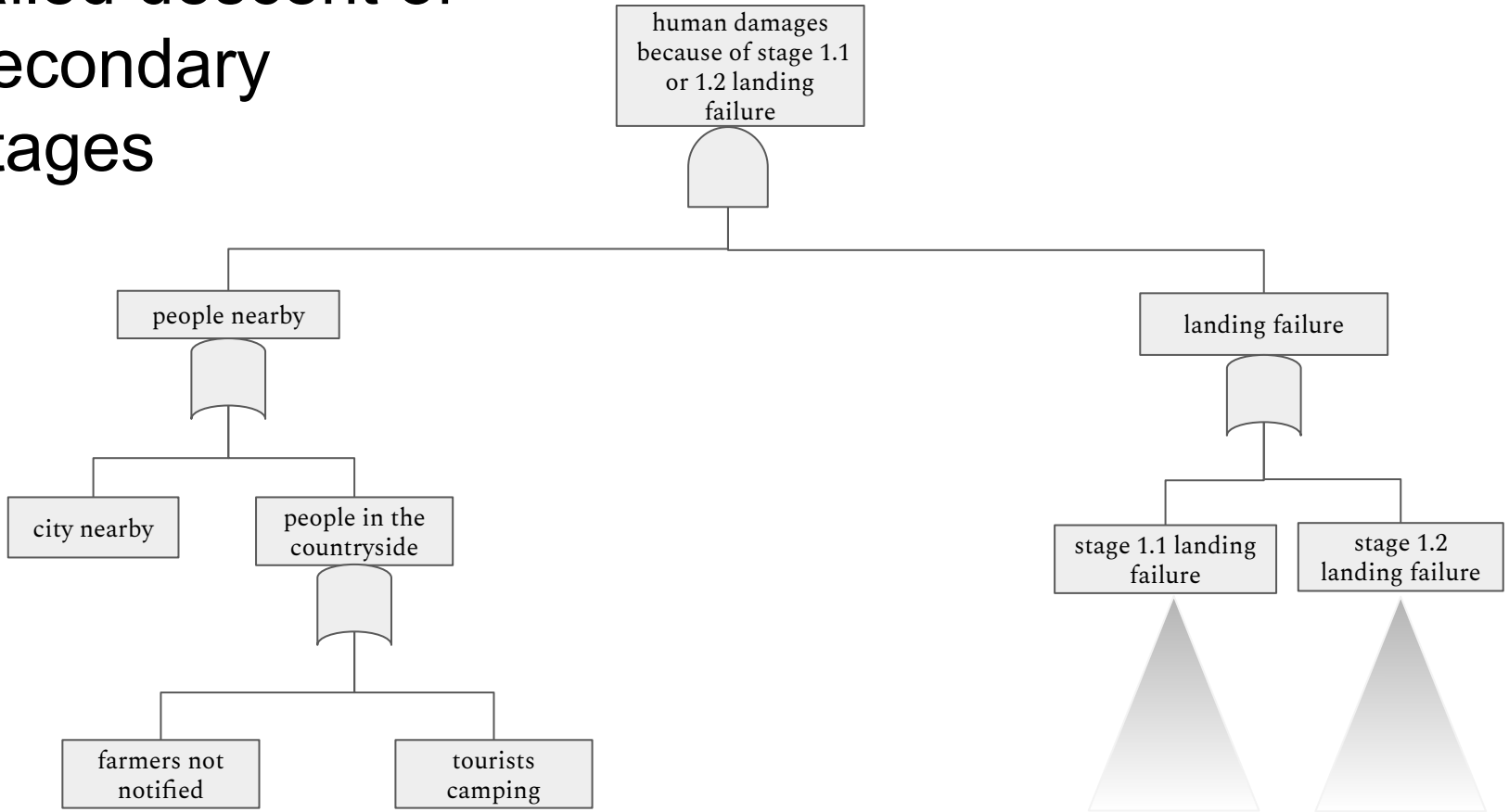
Question: **How does Falcon Heavy compare to Falcon 9?**

failed descent

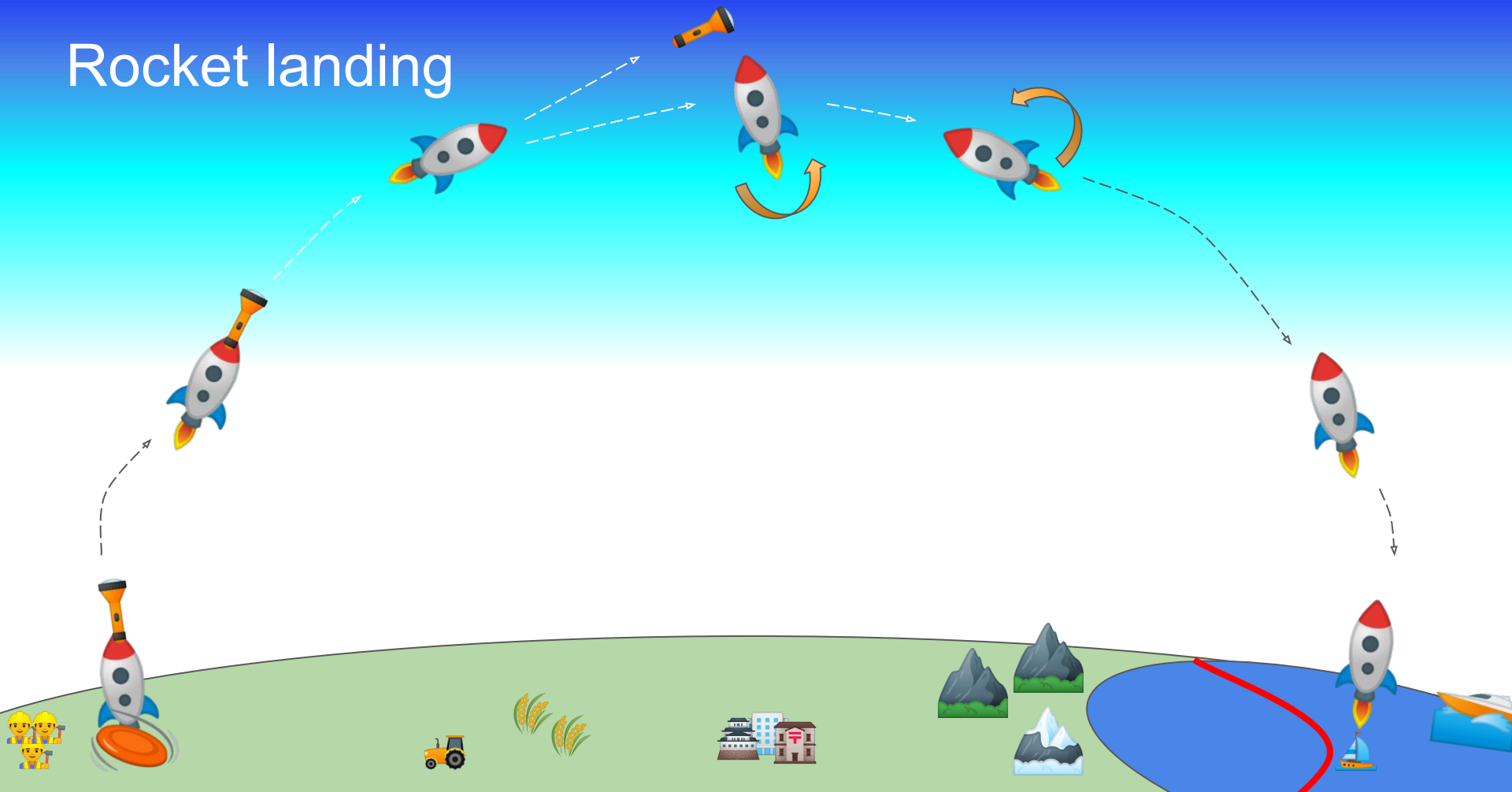


failed descent of secondary stages

Note that tree for stage 1 **landing failure** may be reused for stages 1.1 and 1.2.



Rocket landing



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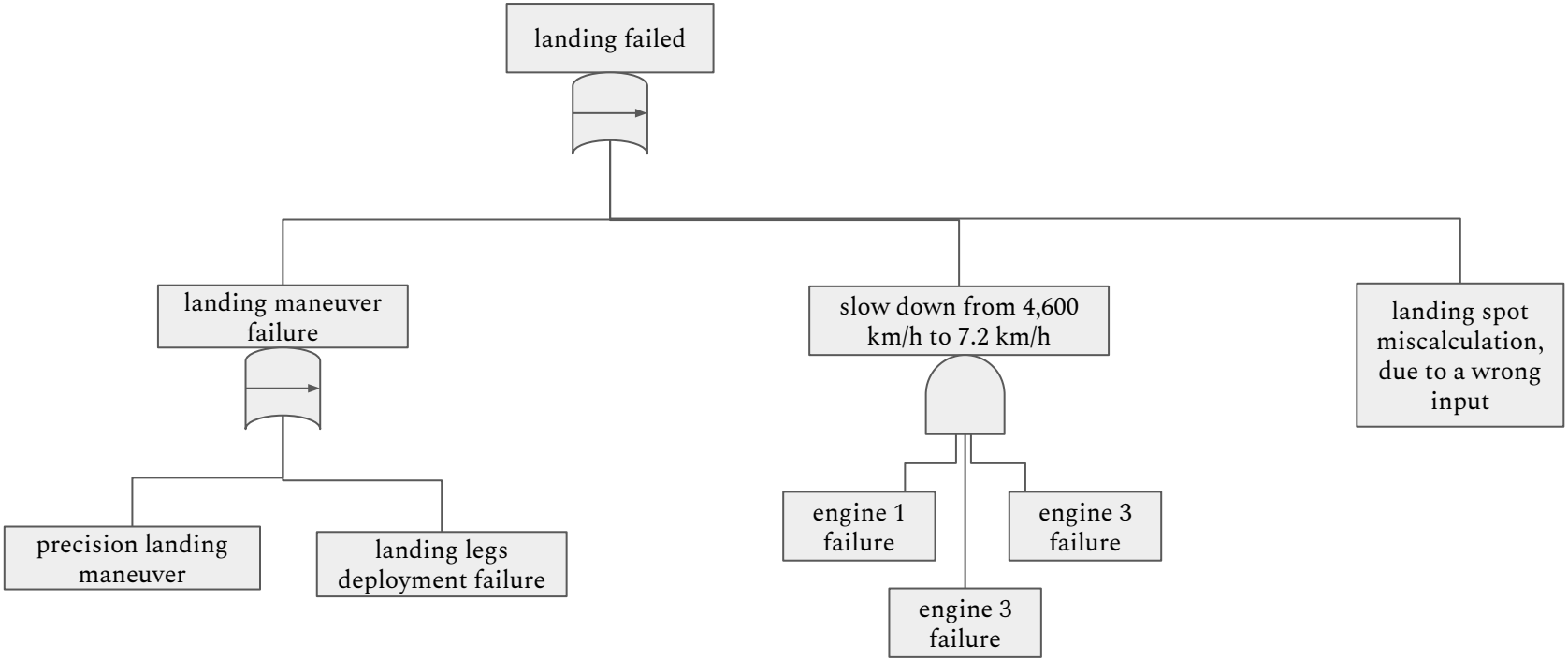

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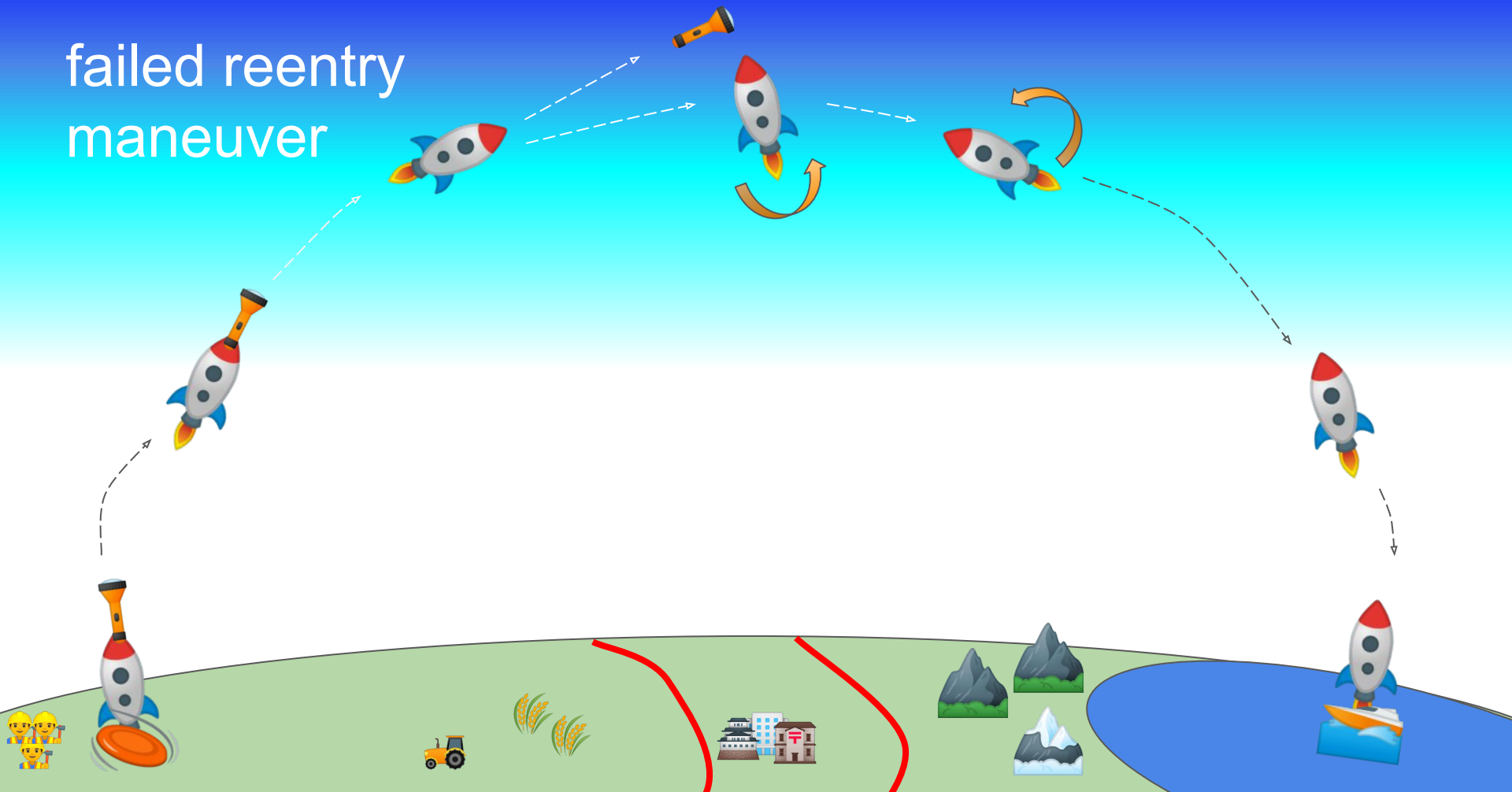
failed reentry maneuver



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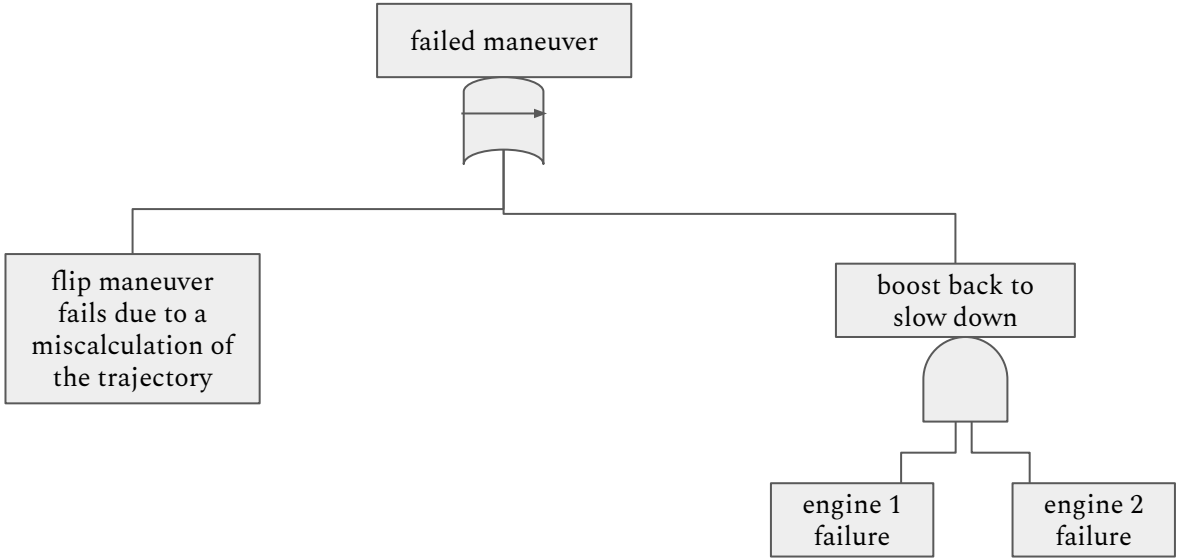
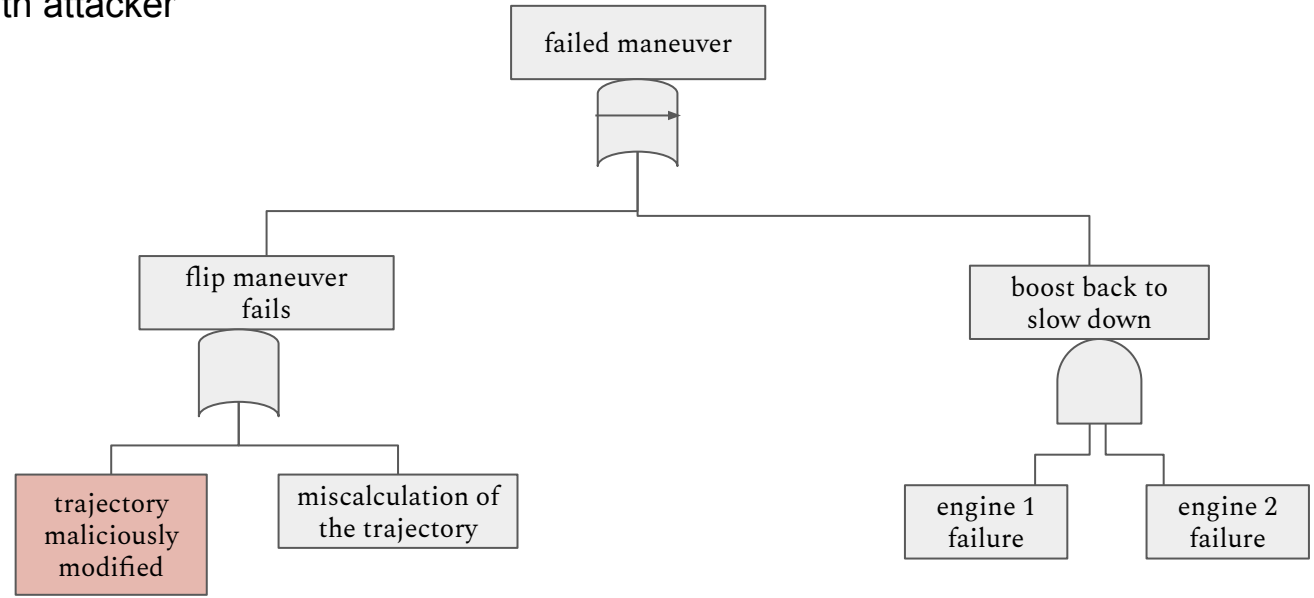
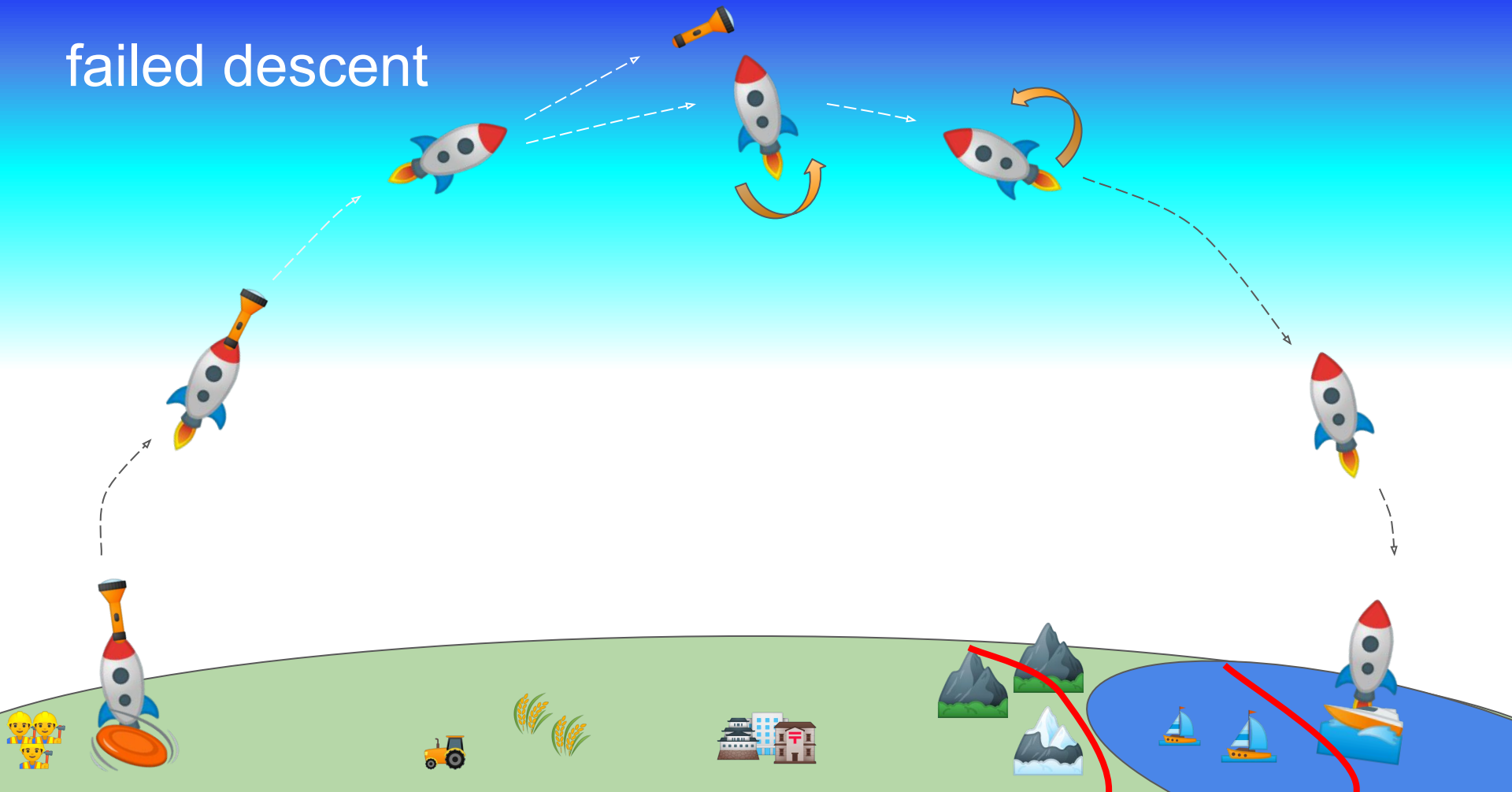


failed reentry maneuver

version with attacker



failed descent



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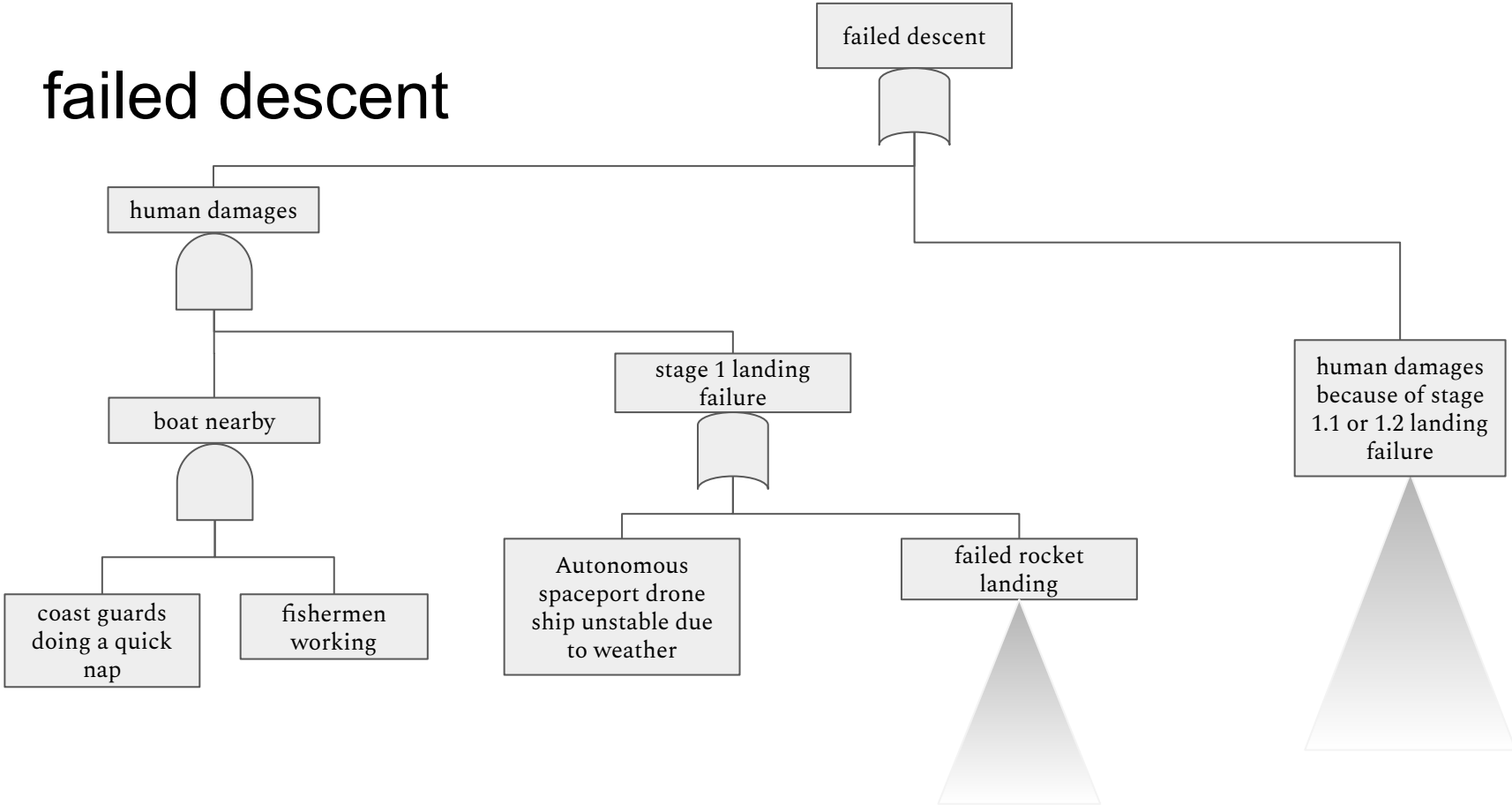

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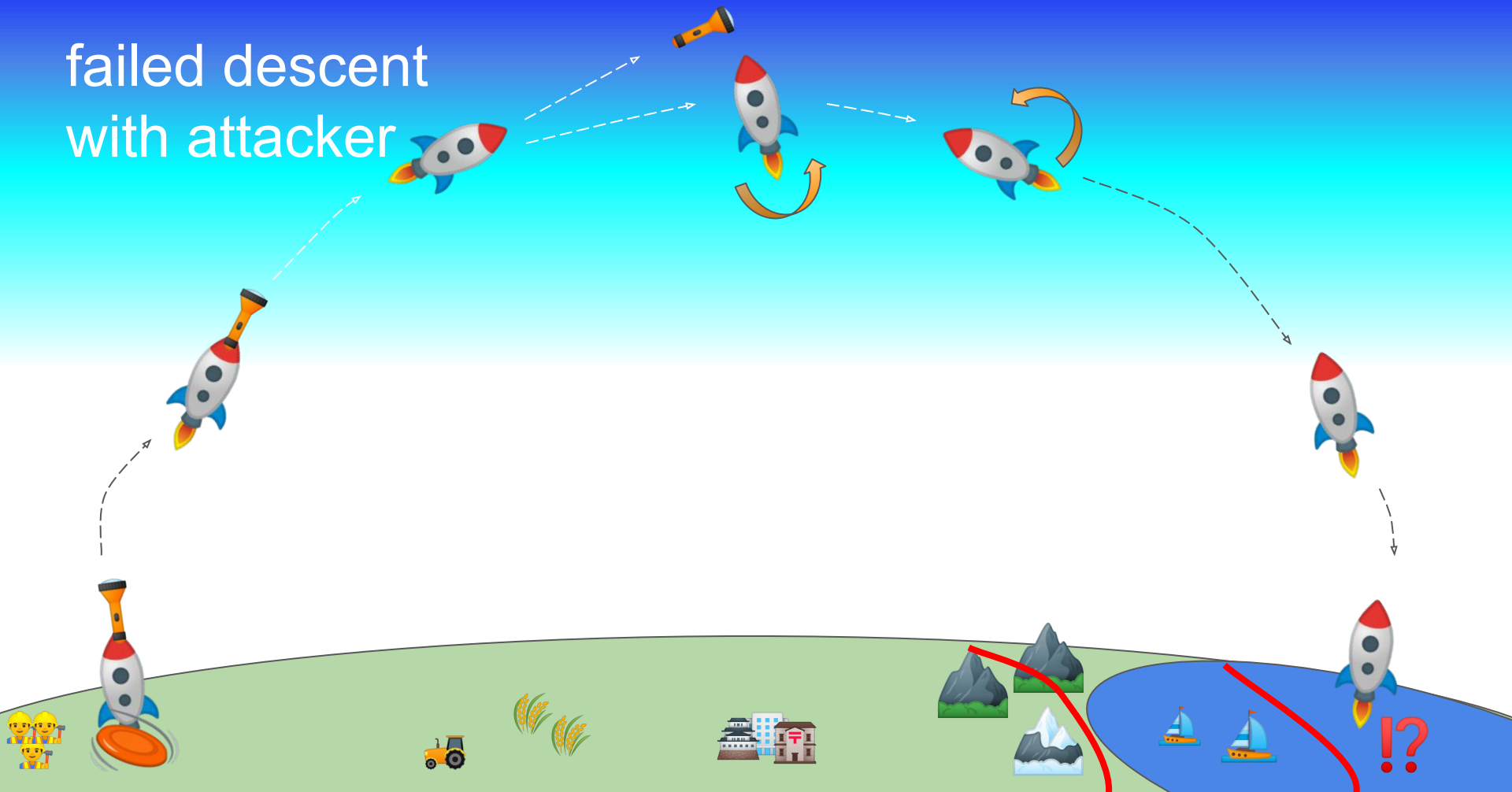
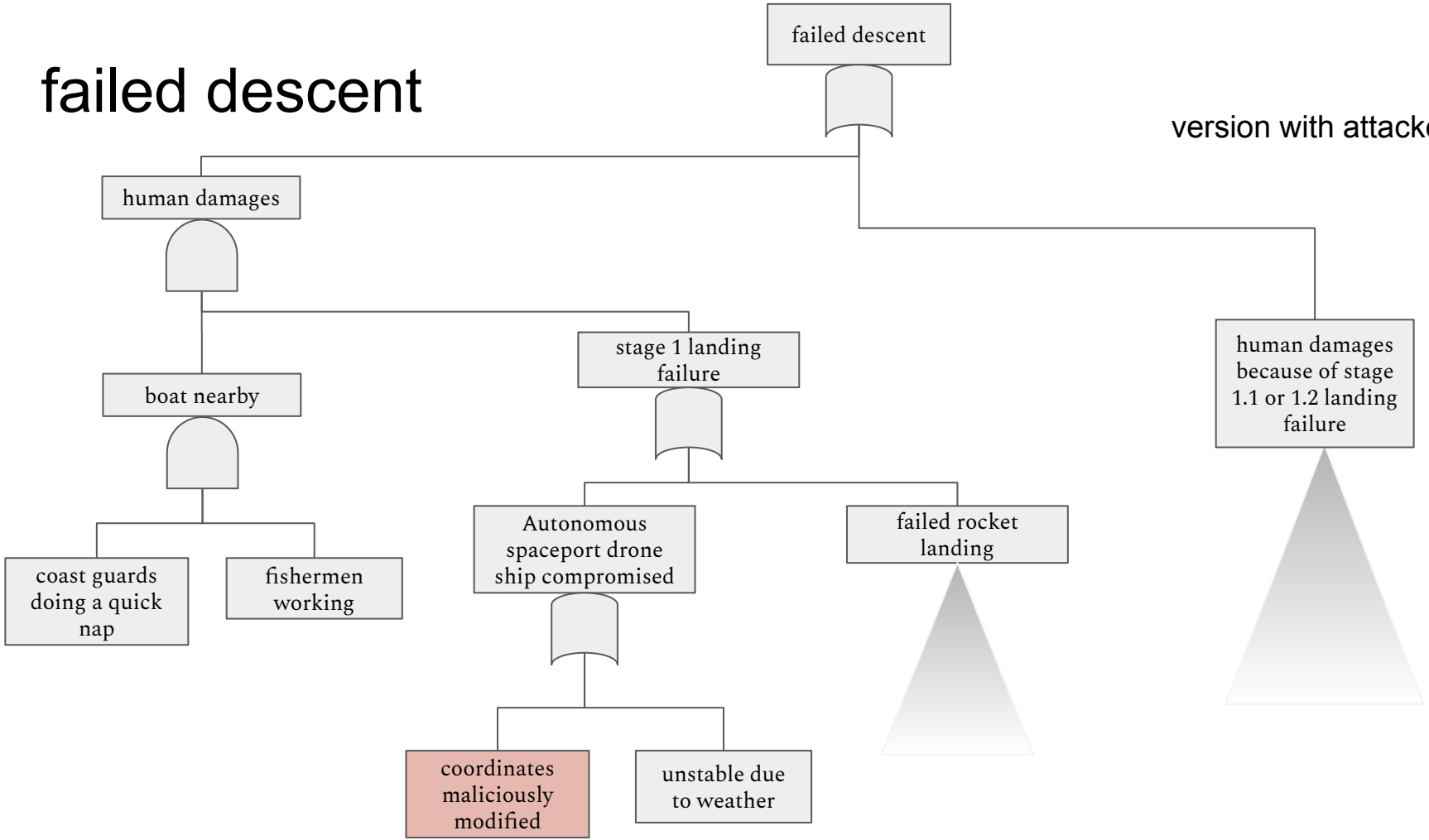
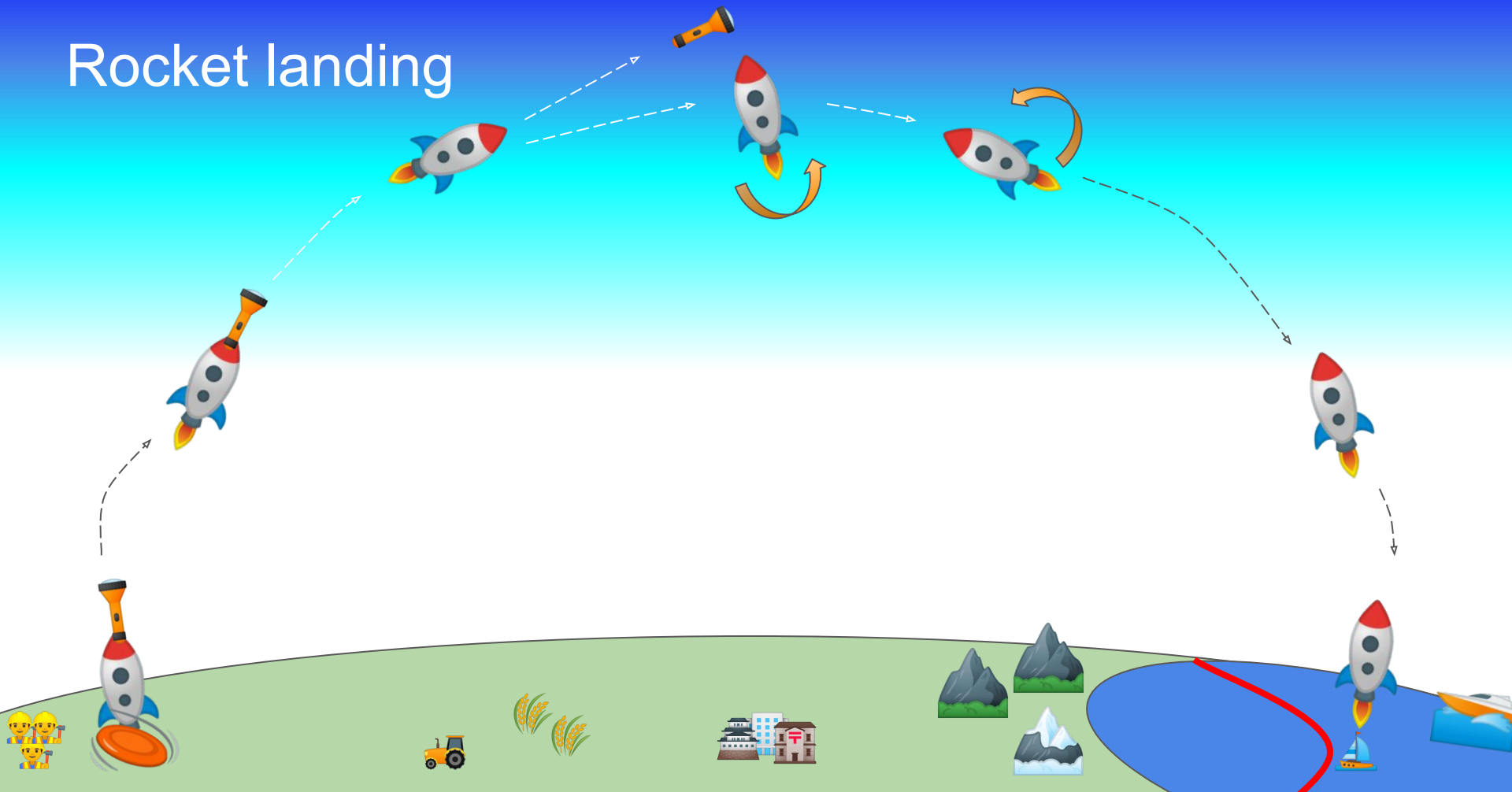


failed descent



Rocket landing



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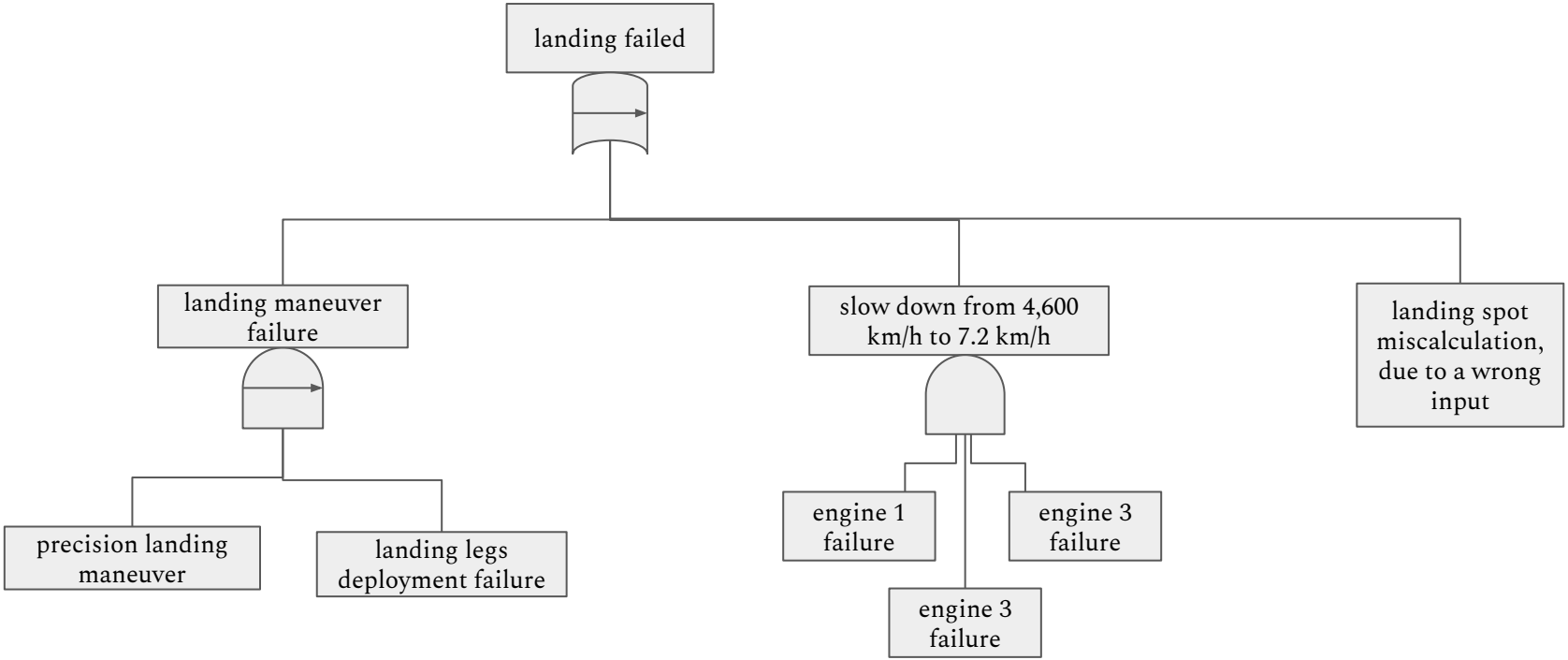
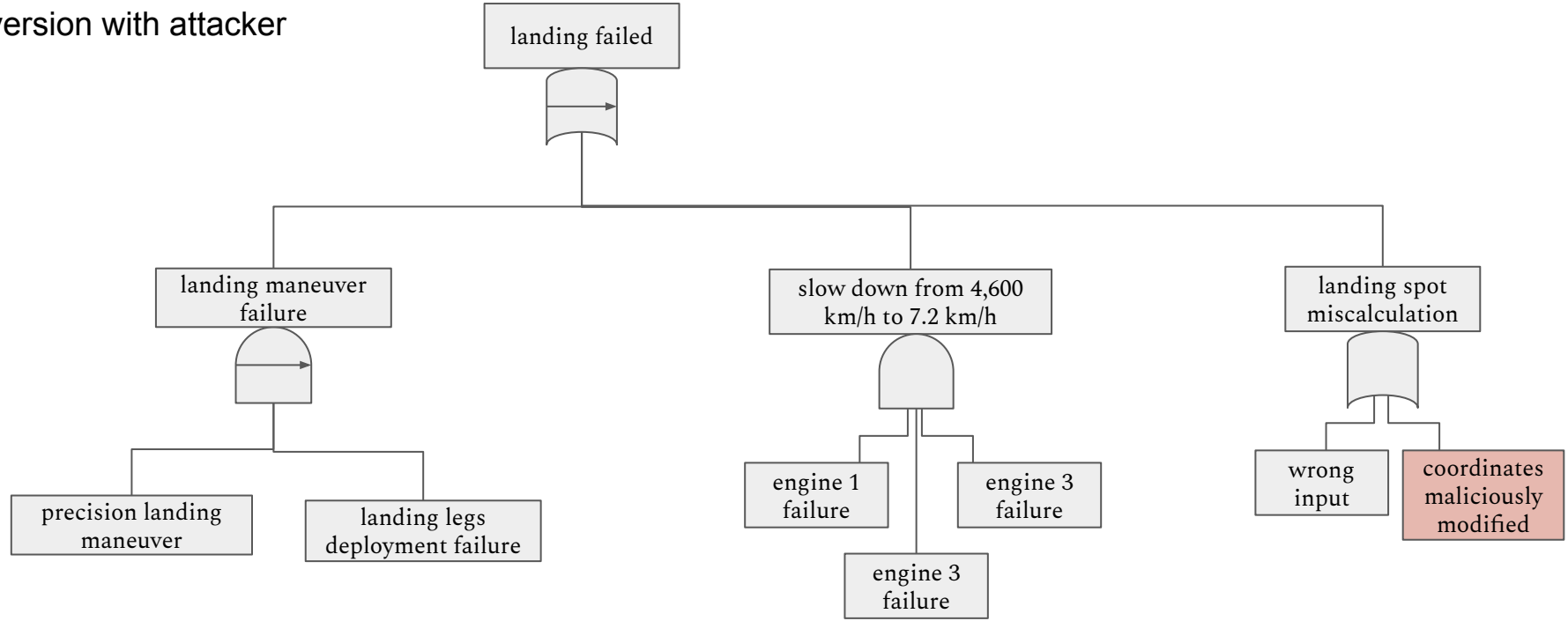
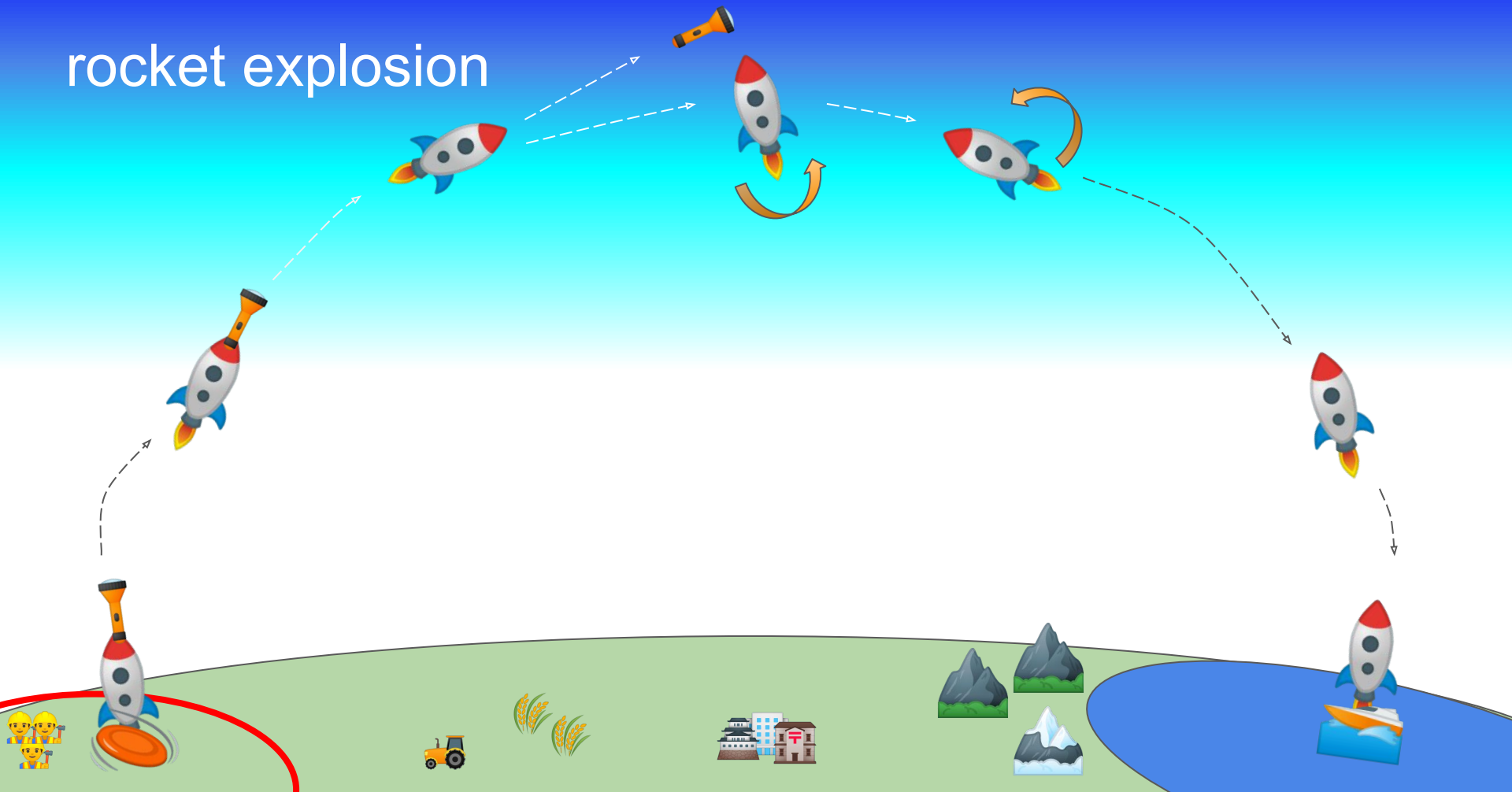


Rocket landing

version with attacker



rocket explosion

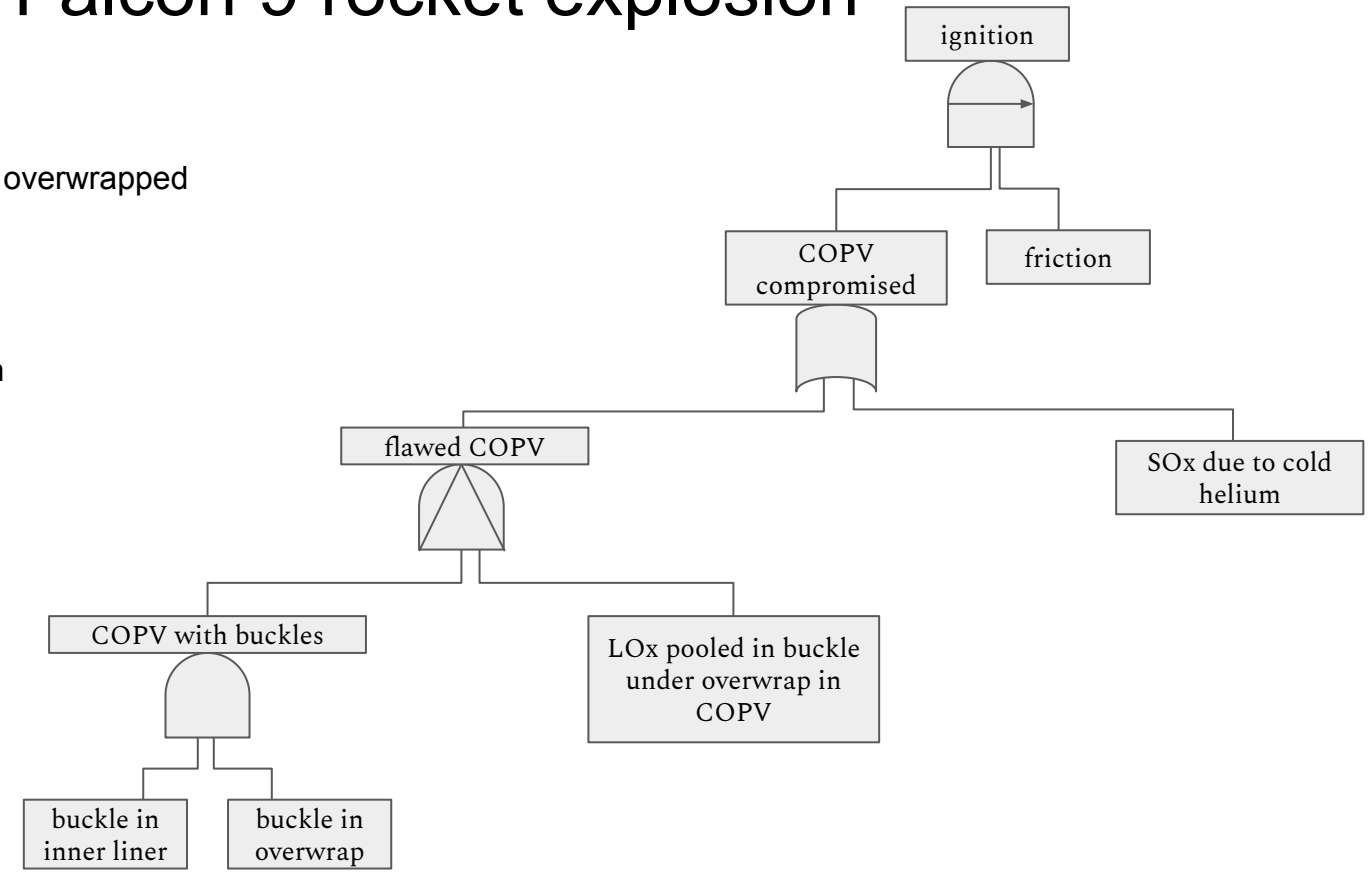


SpaceX Falcon 9 rocket explosion

COPV: composite overwrapped pressure vessel

SOx: solid oxygen

LOx: liquid oxygen



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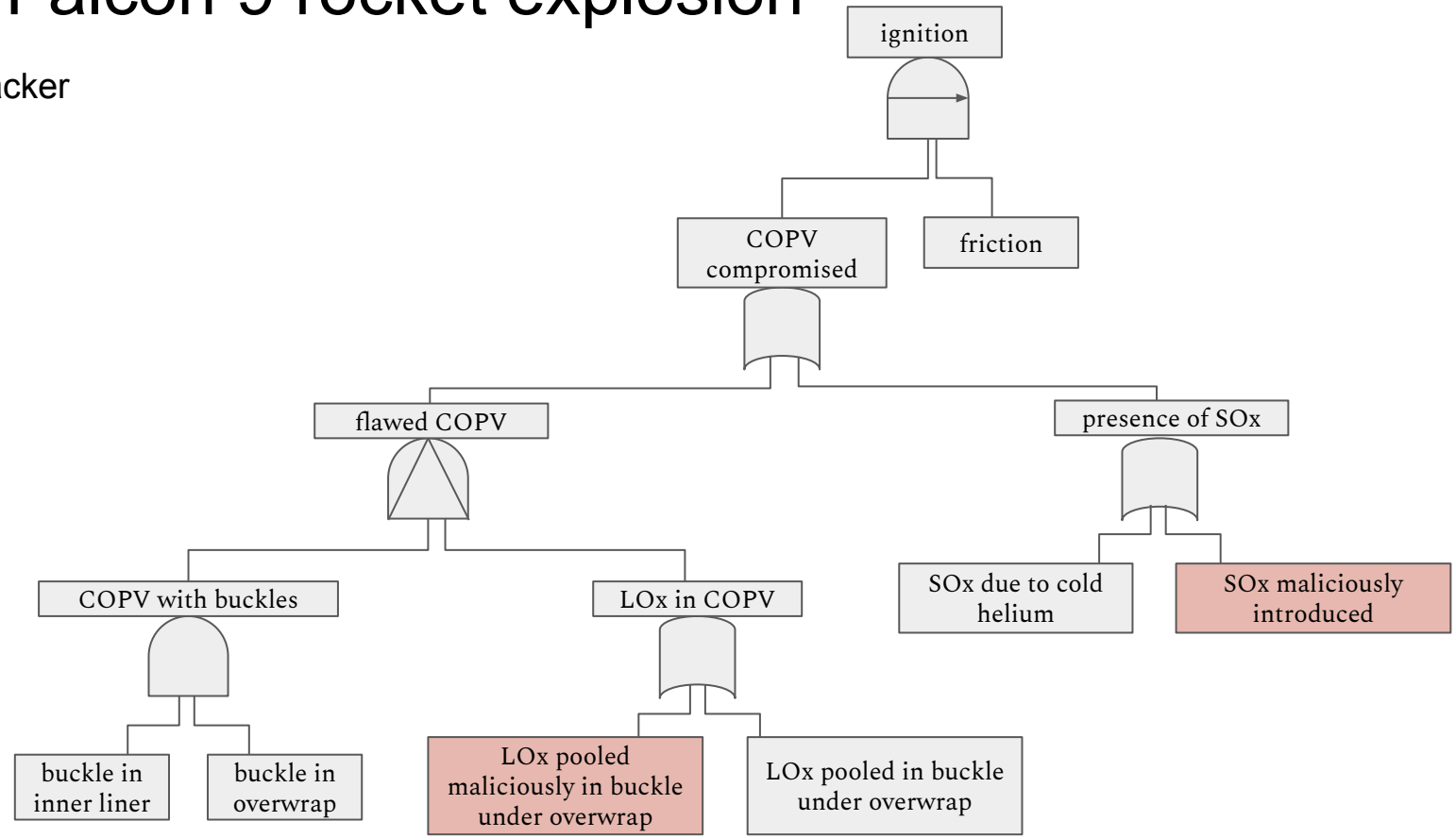

Attackers profiles

enable/disable attacks based on parameters

	no skill	medium skills	highly skilled
no budget			
medium budget			
high budget			

Attackers profiles

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medium budget			
high budget			

is the attack possible or not?
1 or 0
enable or disable

Attackers profiles

enable/disable attacks based on parameters

	no skill	medium skills	highly skilled
no budget			
medium budget			
high budget			

affects the probability of an attack to be successful

Attackers profiles

enable/disable attacks based on parameters

	no skill	medium skills	highly skilled
no budget			
medium budget			
high budget			

affects parameters defining the success of an attack
e.g. time, cost, damages

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Problems we can substantiate:

Question: Do Falcon 9 missions pose less of a risk to humans than conventional missions?

Answer: Yes (by the semantics).

Question: But how much so?

Method: Assign sensible probabilities to periodic events,

and enable/disable attacks according to attacker profiles.

Further risk assessment questions.

Risk assessment questions addressed by reassembling sub-trees:

1. damage to 3rd-party property?

2. damage to assets of business (SpaceX)?

3. cost of failing to deliver payload?