# Enhanced Cargo Compartment Fire Detection: Passive Radio Frequency Identification (RFID)

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Federal Aviation Administration

# Introduction

- **Background:** Unit Load Devices (ULDs) are integral for cargo transportation in aviation. However, their design inadvertently conceals smoke, hindering timely fire detection.
- **Implications:** Concealed fires have led to incidents with overwhelmed onboard fire suppression systems, resulting in tragic accidents.
- **Problem Statement:** The lack of a cost-effective, early fire detection solution remains an unresolved challenge. This increases risks associated with fire outbreaks in ULDs.
- **Objective:** This research is aims to create a cost-efficient, fast, and precise fire detection system to significantly enhance aircraft fire safety.
- **Significance:** Addressing fire detection problems in ULDs is crucial for preventing accidents, protecting cargo, and enhancing air travel safety.

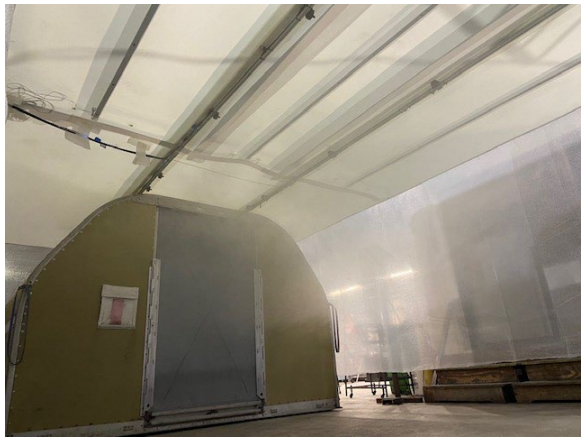
# Limitations

- **Ground experiments:** Conducted experiments on the ground, which may differ from conditions within in-flight aircraft cargo compartments.
- **Empty ULD:** Experiments were performed in an empty ULD and may vary from ULDs loaded with cargo.
- **Single ULD style:** Experiments utilized a single style of ULD. However, ULDs come in diverse shapes, sizes, and materials.’

# ULD overview

The main purpose of a ULD is to secure cargo inside of an aircraft so that the cargo does not move during flight.

- **Types of ULDs and materials**
  - All aluminum
  - Aluminum frame and polymer panels
  - *Aluminum frame and fire resistant panels*
  - Enclosed container (top)
  - Palletized load (bottom)



Enclosed fire resistant container (FRC) ULD

Palletized load fire containment cover (FCC) ULD

# Recent catastrophic aircraft fires

- Between 2006 and 2011, three catastrophic in-flight aircraft fires originated inside of ULDs [1].

**February 7, 2006**
**UPS Flight 1307**

- Crew fatalities 0/3
- Aircraft destroyed

**September 4, 2010**
**UPS Flight 6**

- Crew fatalities 2/2
- Aircraft destroyed

**July 28, 2011**
**Asiana Flight 991**

- Crew fatalities 2/2
- Aircraft destroyed

- These incidents underline the importance of early fire detection in cargo compartments.
- Lithium batteries are a notable risk factor, significantly escalating fire hazards.
- Between March 3, 2006 and July 13, 2022, there were **98 aviation related incidents** involving lithium batteries on **Cargo aircraft** [2].

[1] National Transportation Safety Board, "Safety Recommendation A-12 -68 through -70," Washington, D.C., 2012.
[2] https://www.faa.gov/hazmat/resources/lithium_batteries/incidents

# Time delays in ULD fire detection

**Time delays in fire detection:**

- Significant time delay from the start of the fire inside the ULD to detection outside.
- Range: 2.5 – 18.5 minutes from fire inside the ULD to detection outside of ULD.

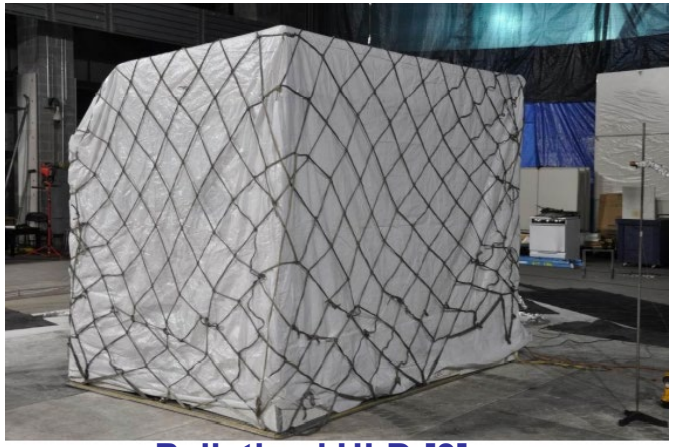
**Rapid Fire Growth:**

- The growth of fires after becoming detectable can be extremely fast.
- Range: 1.9 to 10.5 minutes from detection outside of ULD to peak heat release outside of ULD.

**Implications:**

- Concludes that significant damage to an aircraft can occur shortly after a detectable fire.
- Longer delays may be experienced with palletized ULD.

Smoke exiting rigid ULD [3]



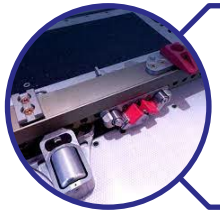
Palletized ULD [3]


[3] National Transportation Safety Board, "Report No. 12-019," Washington D.C., 2012.
[4] T. Wilk, "Smoke Detection Delay Inside a Cargo Container," Federal Aviation Administration (Unpublished), Atlantic City, NJ, 204.
[5] S. Chin, "The Scalability of Smoke Detectors and the Viability of New Detection Methods in Aircraft," Federal Aviation Administration, Atlantic City, NJ, 2019.
[6] J. Wood, "Strategies for Improved Fire Detection Response Times in Aircraft Cargo Compartments," Federal Aviation Administration, Atlantic City, NJ, 2020.

# ULD fire detection systems

Air sampling smoke detector (ASSD)

Battery powered wireless smoke detector



Telair aircraft power drive heat detector

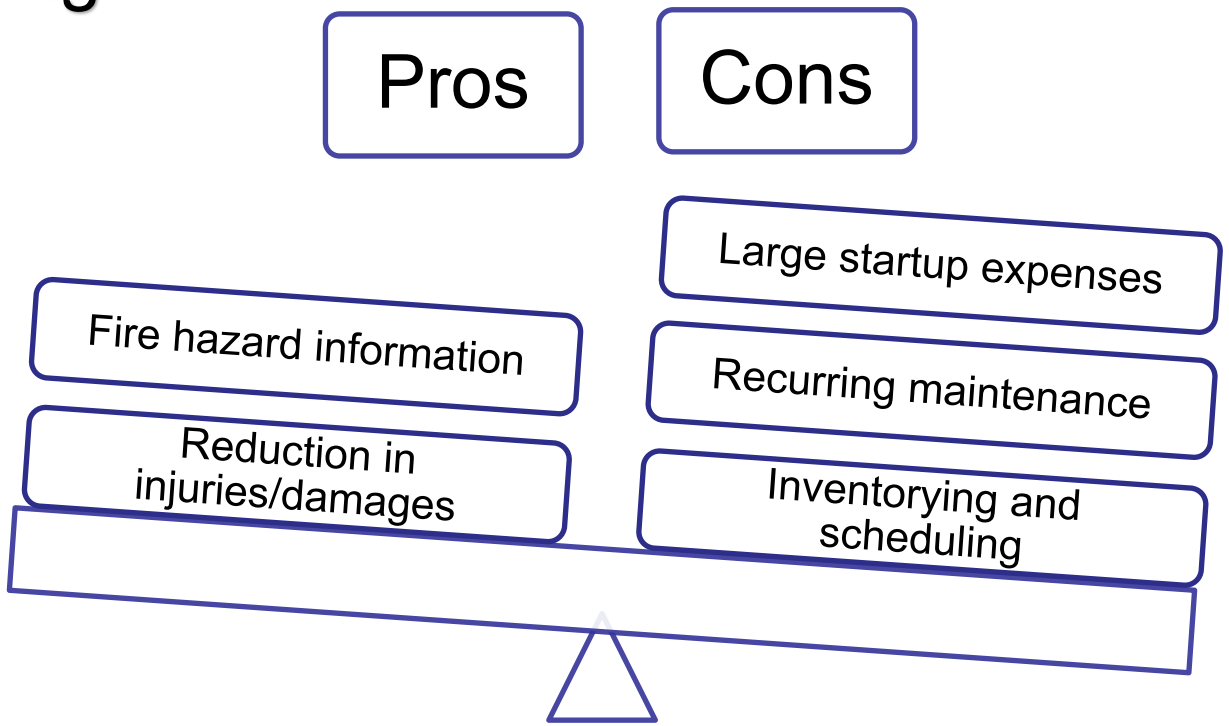
FedEx Express infrared sensor fire detector

[5] S. Chin, "The Scalability of Smoke Detectors and the Viability of New Detection Methods in Aircraft," Federal Aviation Administration, Atlantic City, NJ, 2019.
[6] J. Wood, "Strategies for Improved Fire Detection Response Times in Aircraft Cargo Compartments," Federal Aviation Administration, Atlantic City, NJ, 2020.
[7] Telair, "CONTACT-LESS ULD TEMPERATURE SENSING WARNING SYSTEM," [Online]. Available: https://telair.com/portfolio-item/contact-less-uld-temperature-sensing-warning-system/?nowprocket=1. [Accessed 13 02 2022].
[8] Federal Aviation Administration, "VENTS WITH SMOKE, FIRE, EXTREME HEAT OR EXPLOSION INVOLVING LITHIUM BATTERIES," 30 June 2021. [Online]. Available: https://www.faa.gov/hazmat/resources/lithium_batteries/media/Battery_incident_chart.pdf. [Accessed 6 July 2021].

# Cost/benefit of current ULD fire detection

Additional time for emergency landing decision making

High costs for over one million ULDs currently in use



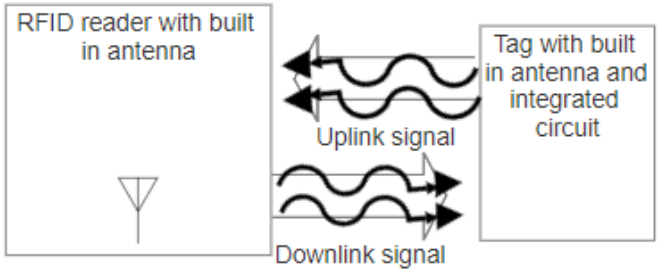

**Issues with current technology:**

- **Battery Changes:** Wireless smoke detectors need frequent battery replacements.
- **Tubing Maintenance:** ASSD systems require regular tubing installation/removal.

[9] International Air Transport Association, "Unit Load Devices (ULD)," [Online]. Available: https://www.iata.org/en/programs/cargo/unit-load-devices/#:~:text=With%20about%201%20million%20aircraft%20ULDs%20in%20service,aircraft%20parts%20and%20directly%20contribute%20to%20flight%20safety.. [Accessed 14 02 2022].

# UHF RFID overview

- **Inexpensive:** Cost-effective solution for various applications.
- **Communication:** Utilizes electromagnetic radio waves for communication with readers via antennas.
- **Material compatibility:** Reads through composites but not through metal.
- **Passive tags:** Integrated circuits (IC) in passive tags are powered solely b received electromagnetic waves.
- **Communication method:** Employs backscattered communication to interact with the reader.
- **Non-line of sight:** Can collect data from multiple tags (approximately 30 reads/second) without requiring a direct line of sight.
- **Sensor capabilities:** Possible to sense physical parameters such as temperature and location.




**UHF RFID basic schematic**

[10] K. Finkenzeller, RFID Handbook Second Edition, West Sussex, England: John Wiley & Sons Ltd., 2003

# Temperature sensing tag overview

- Passive wireless sensor IC
- On-chip temperature sensor
- User-accessible memory for data storage
- **Range**: -40°C to 125°C
- **Accuracy**: ±0.5°C (30 to 60°C)


**Temperature sensing tag**

# Test setup

**ULD configuration**

- Fire ULD
  - This ULD is contains either a controlled or real fire scenario
  - It includes a light obscuration meter to measure smoke production and temperature sensors to measure heat production
- Reference ULD
  - This ULD serves as a control unit without any heat input
  - It is instrumented with temperature sensors to measure baseline temperature

**Fire ULD (left) and reference ULD (right)**

# Test setup continued

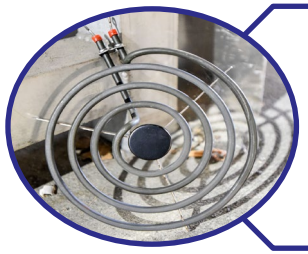
**Test setup components**

- Mock cargo compartment ceiling
  - 6.1m x 3.7m x 2.1m (L x W x H)
  - Positioned 7.6cm above the ULDs
  - Perimeter wrapped in vinyl cover
- RFID readers
  - One reader is positioned directly above the fire ULD
  - One reader is positioned directly above the reference ULD

**Mock cargo compartment**

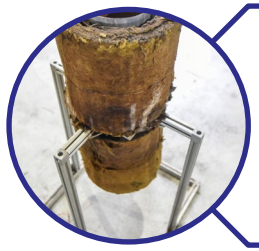
# Varying fuel source

## Controlled fire scenario



Electric heater and smoke generator

## Real fire scenarios

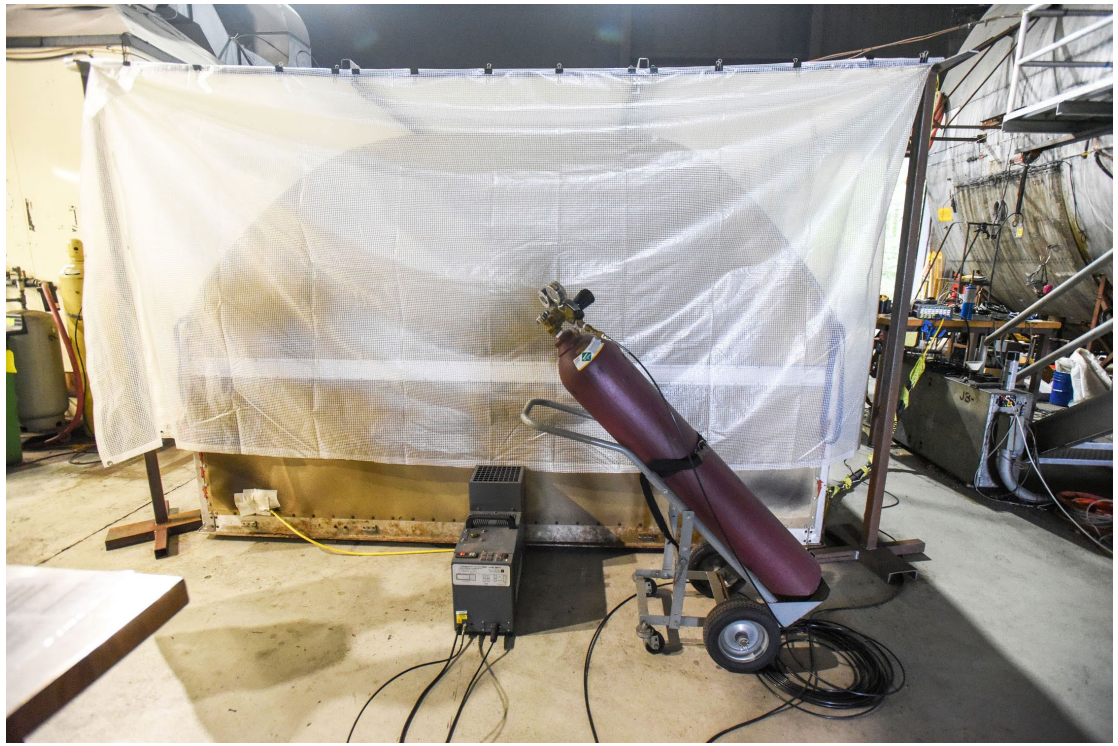


Self sustained smolder

Lithium ion cells

# Electric heater and smoke generator test

- **Smoke Generator:** Positioned externally, piped to deliver cold smoke inside the ULD.
- **Smoke output:** Standardized for certifying aircraft cargo compartment smoke detection systems.
- **Heater:** Positioned at the interior center floor of the ULD.
- **Heater output:** varied using a variable AC transformer.
- This setup is intended to simulate and evaluate fire detection under controlled heating conditions.



**Smoke generator providing consistent smoke**

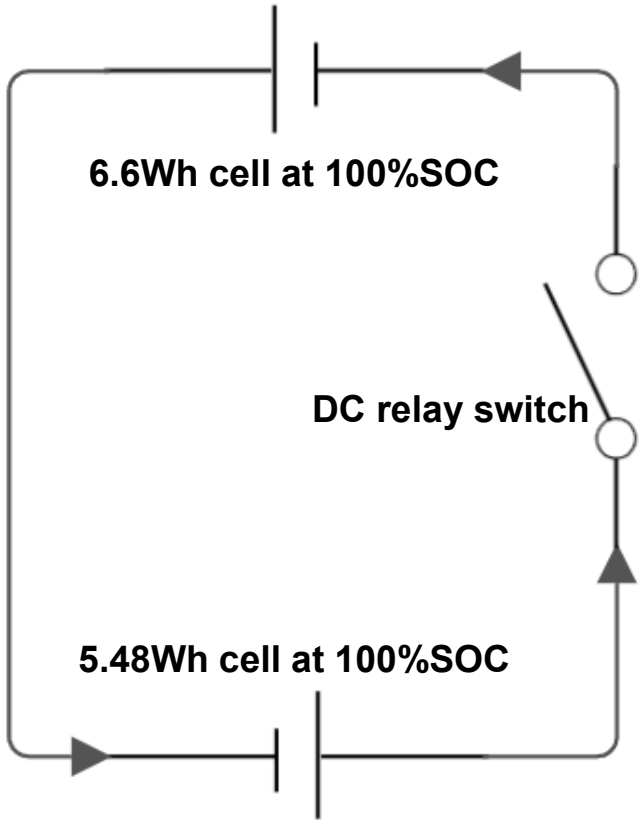
# Smoldering fire test setup

- **Pipe:** Aluminum, 15.24cm diameter, 58.88cm length.
- **Position:** Vertical, 33cm above ground.
- **Insulation**: 5.08cm thick Mineral Wool, R-value 8.7.
- **Fuel source:** 620g low ash hardwood pellets.
- **Ignition:** Pellets ignited at the bottom using fire.
- **Purpose:** To sustain a smolder and progressively intensify the fire throughout the test duration without added heat.

**Insulated aluminum pipe with smoldering wood pellets**

# Lithium-ion battery fire test setup

- **Battery:** Two lithium cobalt oxide pouch cells
- **Battery capacities:** 5.48Wh and 6.6Wh
- **State of charge:** 100%
- **Insulation:** Wrapped on five sides with 3.8cm thick ceramic fiber insulation board
- **Ignition:** User activated relay for short circuit. This can lead to thermal runaway in lithium-ion batteries by allowing excessive current flow, resulting in uncontrollable heating.
- **Purpose:** To initiate thermal lithium-ion thermal runaway without added heat.

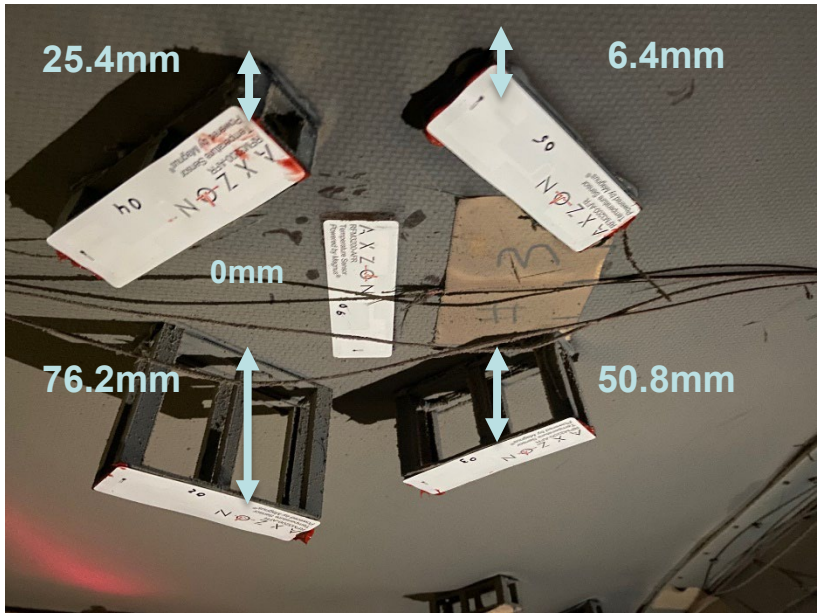



**Schematic of short circuit battery and switch (left)**
**Battery insulation for testing (right)**

# Sensor configuration

**Fire ULD**

- **Interior ceiling sensors (located at ULD center)**
  - One sensor positioned on the ULD ceiling (0mm)
  - Four sensors attached to mounts on the ceiling at varying heights (6.4mm, 25.4mm, 50.8mm, and 76.2mm)
- **Exterior ceiling sensor (located at ULD center)**
  - One sensor positioned on the ULD ceiling (-3.175mm)




**ULD temperature sensor placement**

**Reference ULD**

- **Interior ceiling sensor (located at ULD center)**
  - One sensor attached to a mount on the ceiling (6.4mm)

**The purpose of the mounts is to reduce heat loss from conduction to the ULD surface.**

# Smoke sensor configuration

**Components**

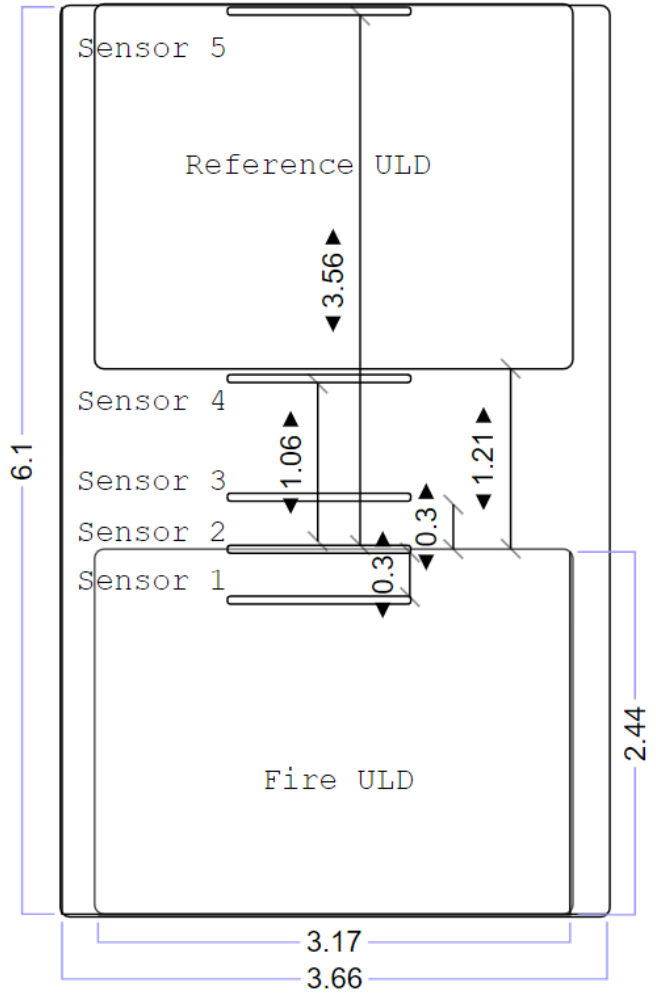
- **Light obscuration meter:** Uses 2.3mW 670nm lasers and silicon diode light sensors to measure light obscuration.
- 1.2m distance between the lasers and the light sensors

**Locations**

- **Fire ULD:** One light obscuration meter positioned at the ceiling
- **Mock cargo compartment:** Five additional light obscuration meters positioned along the ceiling of the ceiling

**Smoke detection threshold**

- **Threshold:**12.5 percent light obscuration per meter (%obs/m) used as the smoke detection threshold these experiments.




**Light obscuration meter locations**

# Future tests

- **In-flight tests:** Future tests should incorporate in-flight tests and data should be reevaluated to determine if ground test activation thresholds are appropriate during flight.
- **Loaded ULDs:** Experiments should be repeated using ULDs loaded with cargo to account for potential variations in fire detection under varying conditions.
- **ULD variety:** To enhance the study's applicability, experiments should encompass a variety of ULD styles, considering different shapes, sizes, and materials commonly used in the aviation industry.

# Timeline

June 2021

Propose solution for early ULD fire detection

June 2021 – March 2022

Review RFID technology, ULDs, and fire detection literature

March 2022 – September 2023

Setup and analyze experiments

January 2024

Release final report

# References


- [1] National Transportation Safety Board, "Safety Recommendation A-12 -68 through -70," Washington, D.C., 2012.
- [2] https://www.faa.gov/hazmat/resources/lithium_batteries/incidents
- [3] National Transportation Safety Board, "Report No. 12-019," Washington D.C., 2012.
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- [10] K. Finkenzeller, RFID Handbook Second Edition, West Sussex, England: John Wiley & Sons Ltd., 2003

# Questions and Answers

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