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Fraunhofer IBP
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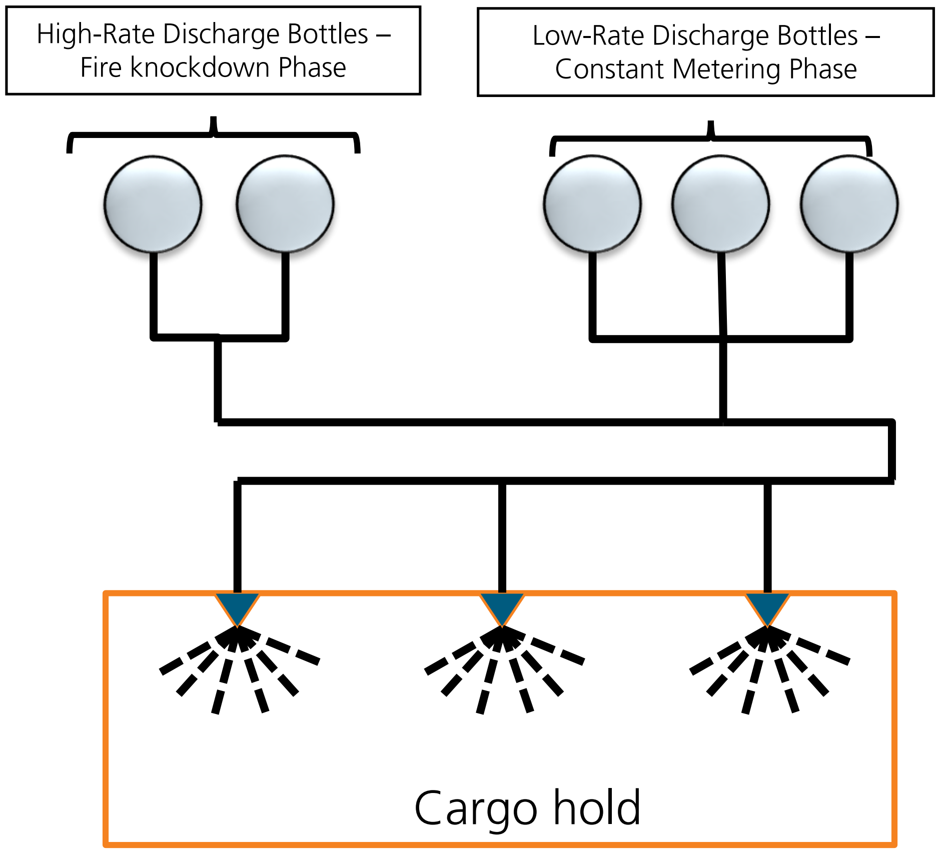
Investigation and modelling of cargo hold fire suppression agent concentration profiles for Halon replacement

Introduction

Existing Aircraft Fire Protection System

Halon based fire protection system

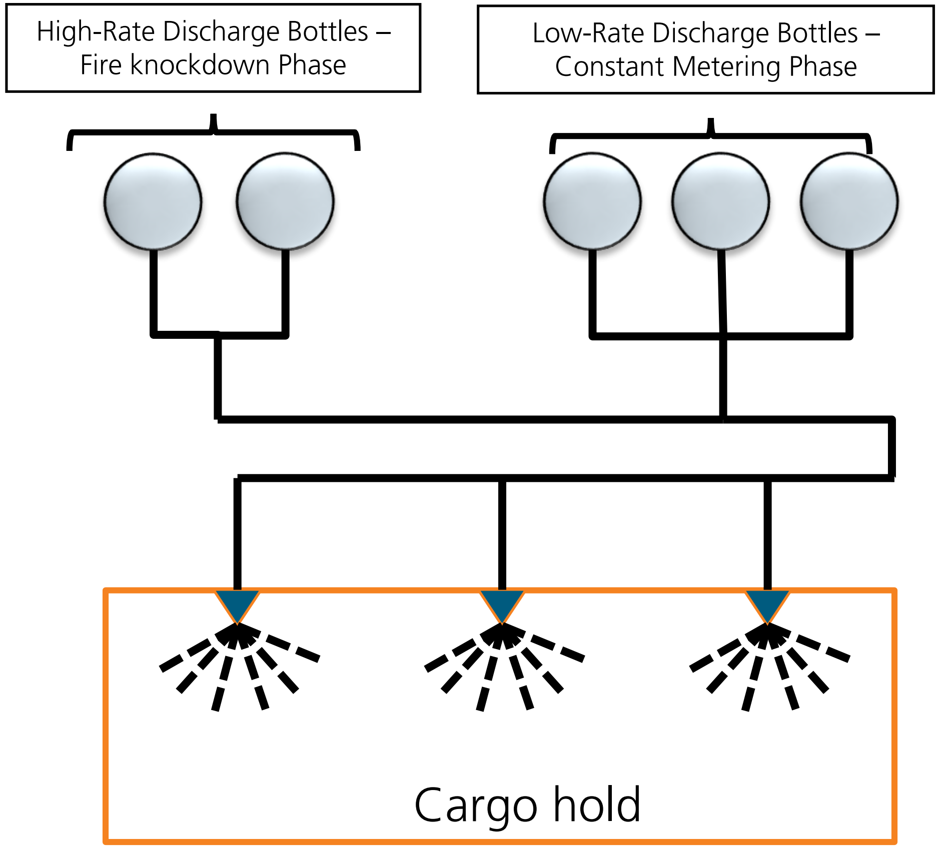
- Discharge nozzles and smoke detectors integrated in cargo ceiling
- After fire / smoke detection:
  - Fire Knockdown Phase:
    rapid release of Halon 1301 knockdown and suppress fire
  - Constant Metering Phase:
    constant discharge of Halon 1301 to maintain the concentration



Environmentally Friendly Fire Protection

Clean Sky 2 Environmentally Friendly Fire Protection System project

- Replacement of Halon due to high GWP and ODP.
- Investigation of alternative agents – here: Nitrogen to dilute oxygen concentration
- Development of sizing tools and models



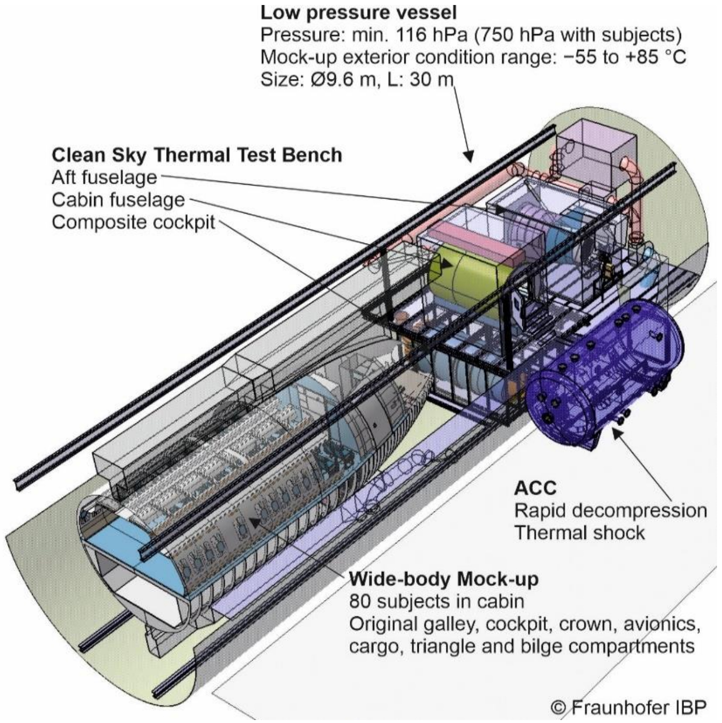
Fraunhofer Flight Test Facility

Low-pressure chamber:

- Length: 30 m
- Replication of flight pressure envelope down to 750 hPa

Cabin air conditions:

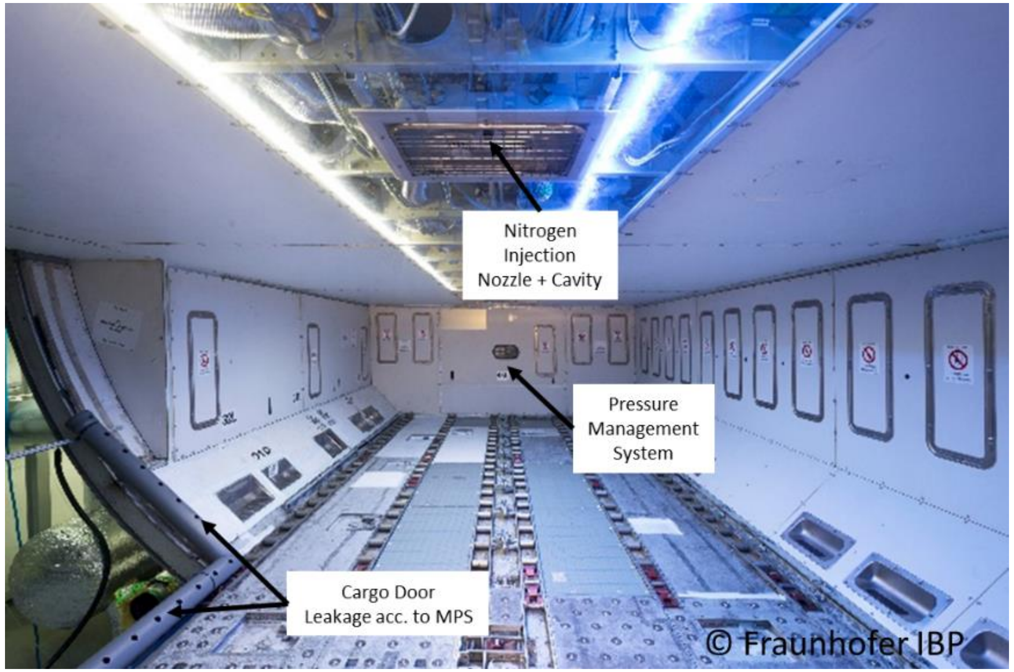
- Air temperature: -20 °C to +30 °C
- Relative humidity: 5 % to 65 % at 20 °C



Test preparations

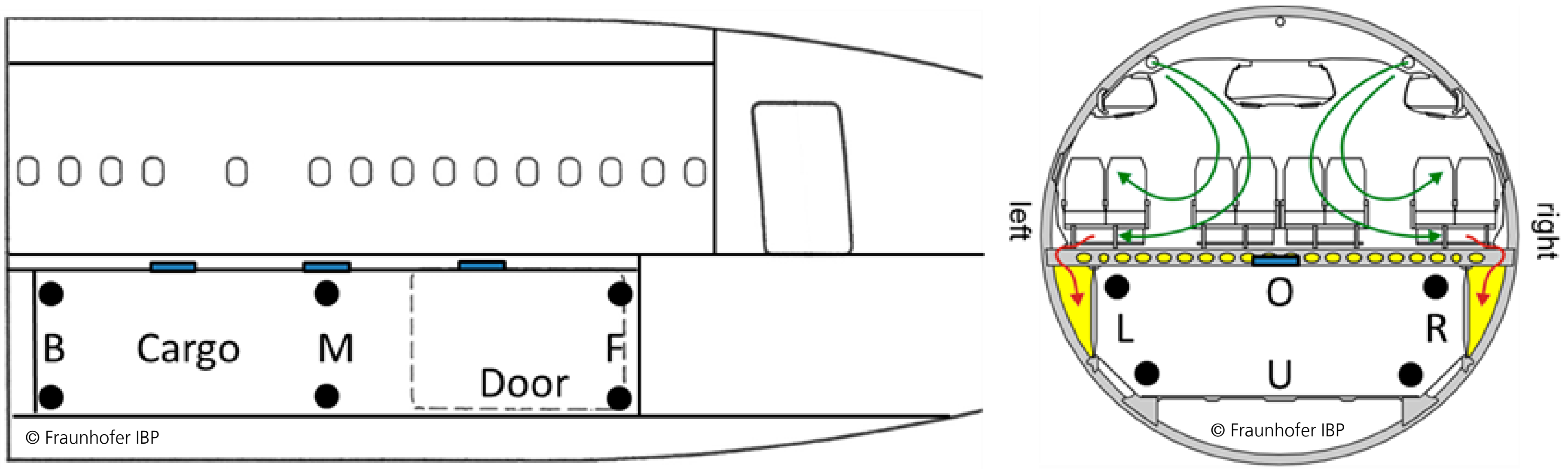
Cargo bay refurbishment

- Original lining and ceiling panels
- Integration of high pressure piping and nozzles
- Integration of the pressure management system
- Cargo door leakage simulation



Test preparations

Cargo bay oxygen sensors



Cargo hold setup

Pressurized nitrogen bottles for knockdown

On-Board Inert Gas Generation System (OBIGGS) for metering

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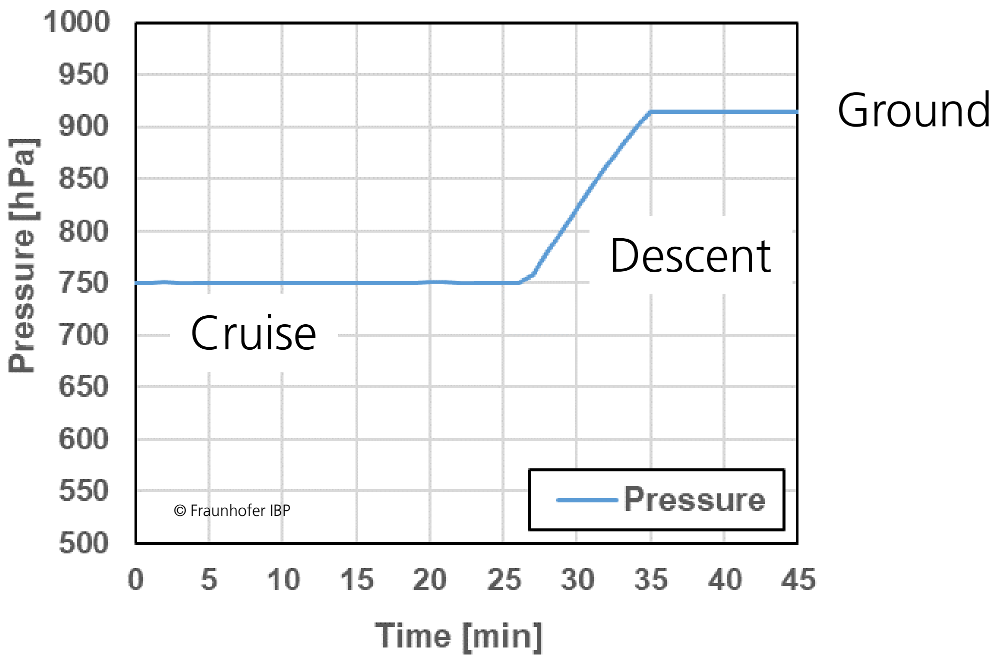
Test configurations

Empty cargo bay

LD3 containers in cargo bay

Exemplary cabin/cargo pressure profile



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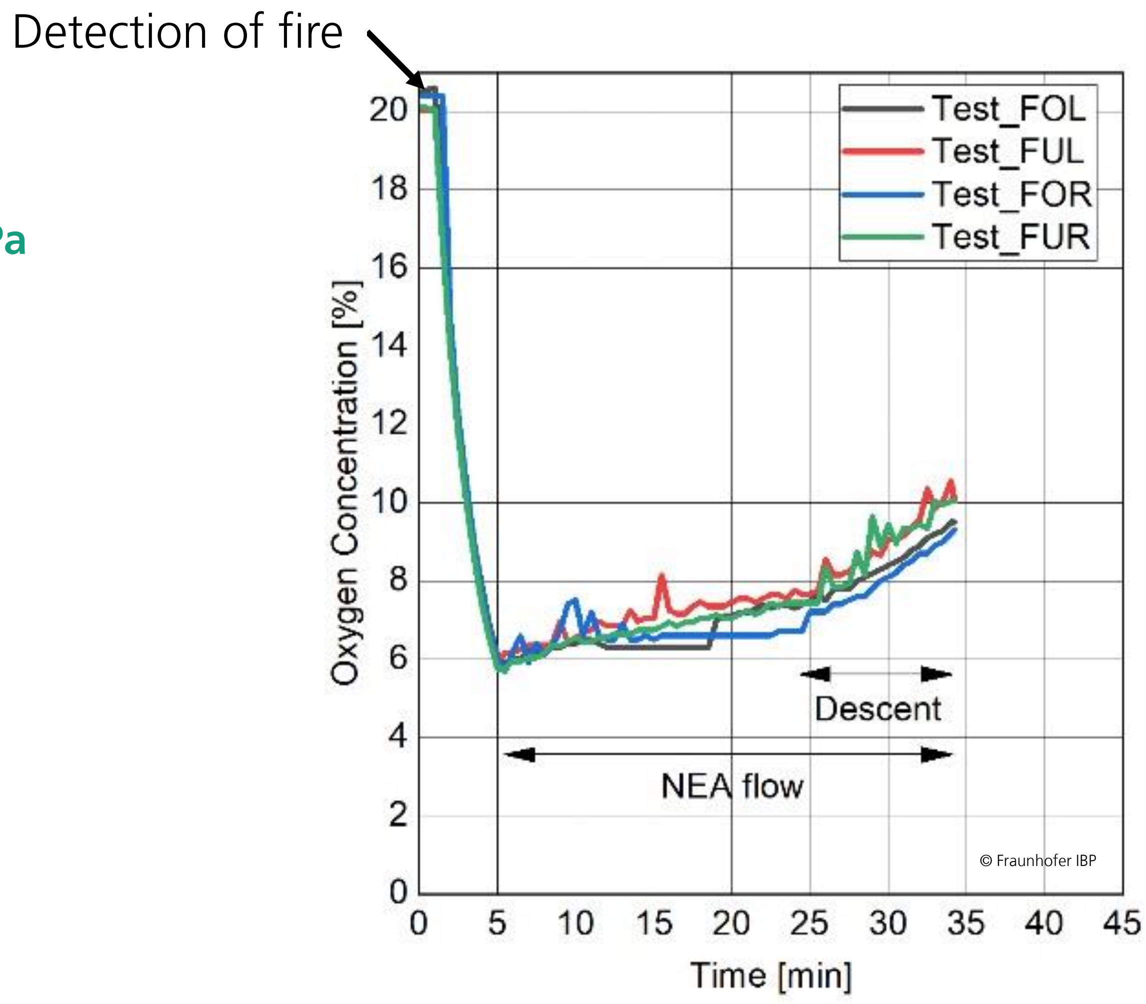
Exemplary concentration profile

Normal cruise

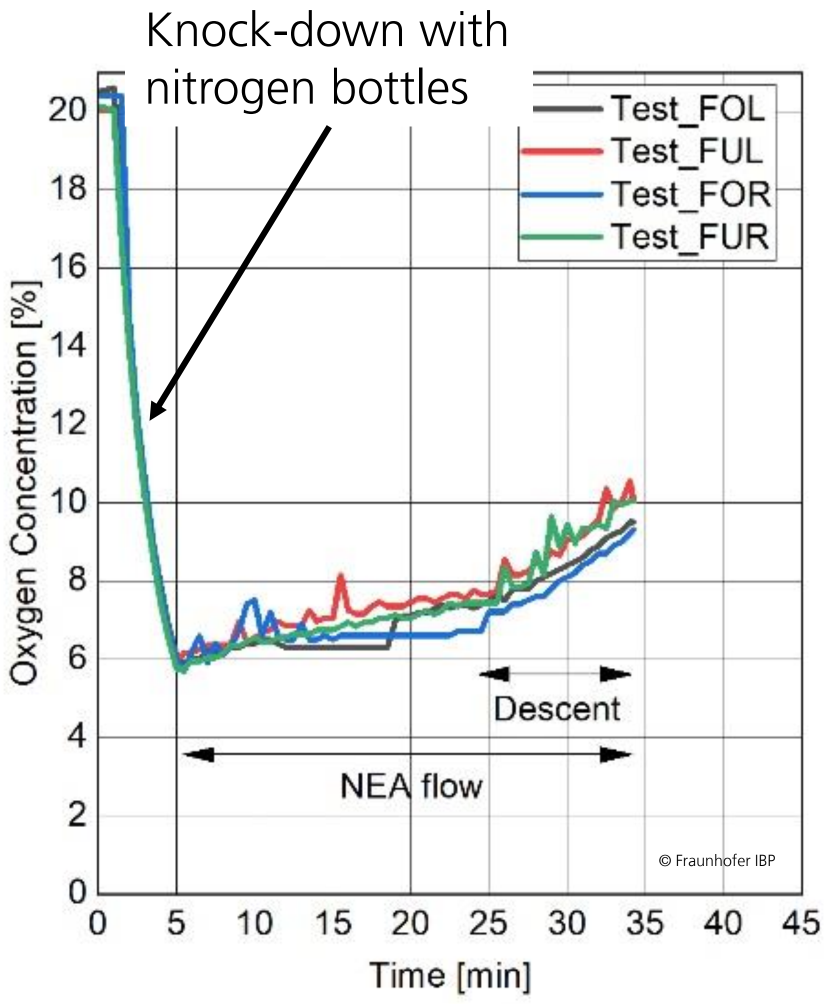
Cabin pressure: 750 hPa



Exemplary concentration profile

Fire protection system activation

Cabin pressure: 750 hPa



Exemplary concentration profile

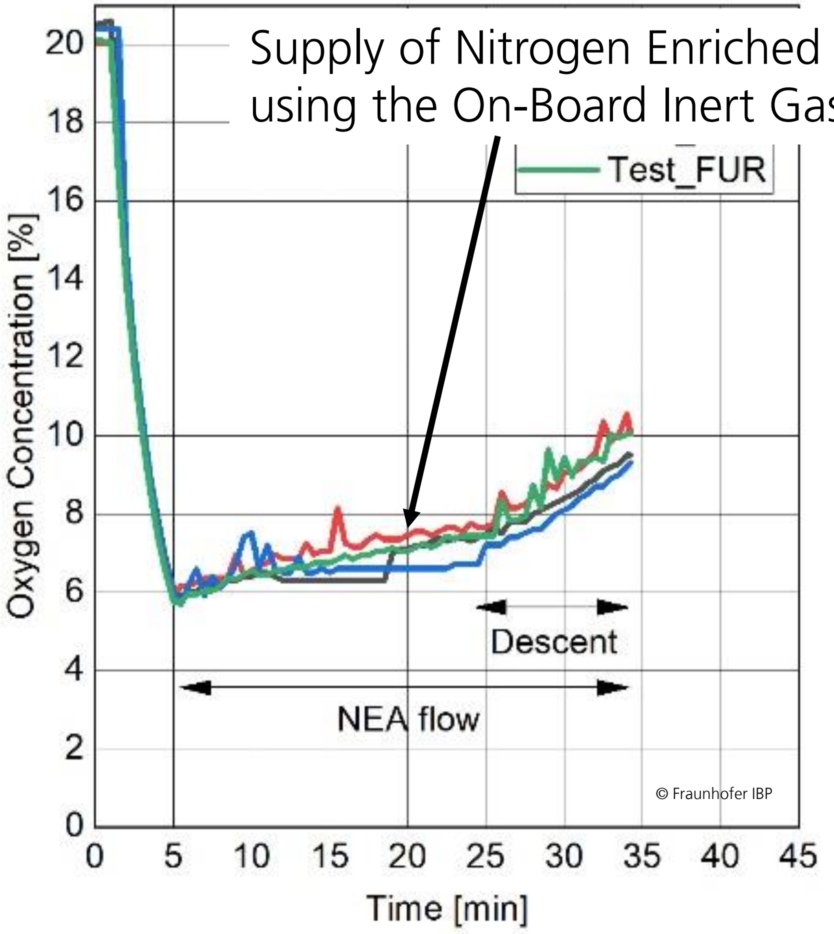
Fire protection system sustaining

Cabin pressure: 750 hPa

Influences on oxygen concentration:

- NEA oxygen concentration
- NEA flow rate
- Air ingress through leakages

Supply of Nitrogen Enriched Air (NEA)
using the On-Board Inert Gas Generation System (OBIGGS)



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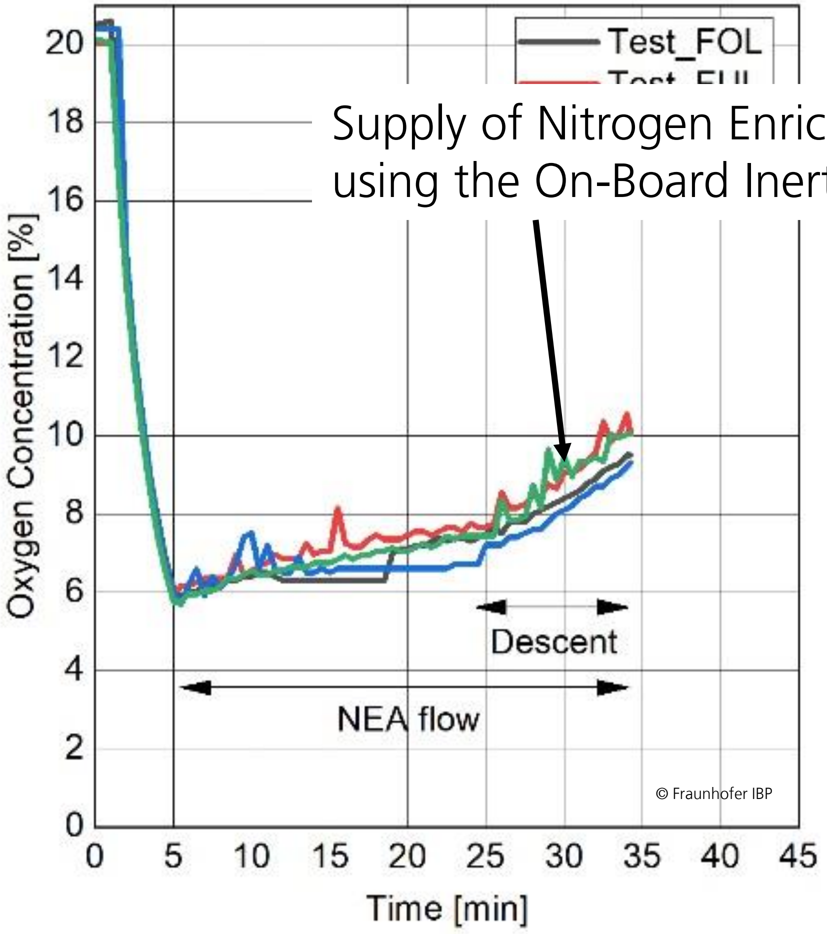
Exemplary concentration profile

Fire protection system sustaining

Descent: Repressurization to ground

Influences on oxygen concentration:

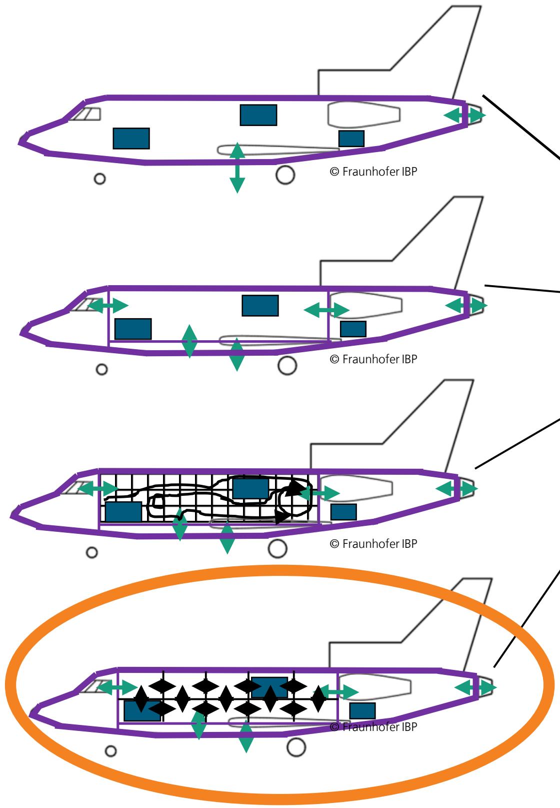
- Forced air ingress due to repressurization
- Rule of thumb:
  750 → 1013 hPa means ¼ of air volume to be added



Supply of Nitrogen Enriched Air (NEA)
using the On-Board Inert Gas Generation System (OBIGGS)

Model Implementation

Zonal Modelling



Modelling Approach	Local Resolution	Speed, Transient
Single-Zone	-	++
Multizone	0	++
CFD	++	--
Zonal	+	+

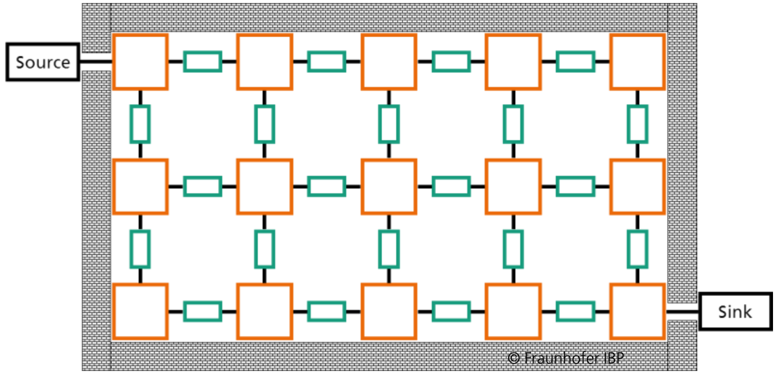
Best compromise

➔ Fraunhofer IESS
(Indoor Environment Simulation Suite)

VEPZO (VElocity Propagating ZOnal Model)

Subdivision of a space into zones (volumes)

- Volume model:
  - Mass Conservation of species
  - Conservation of thermal energy



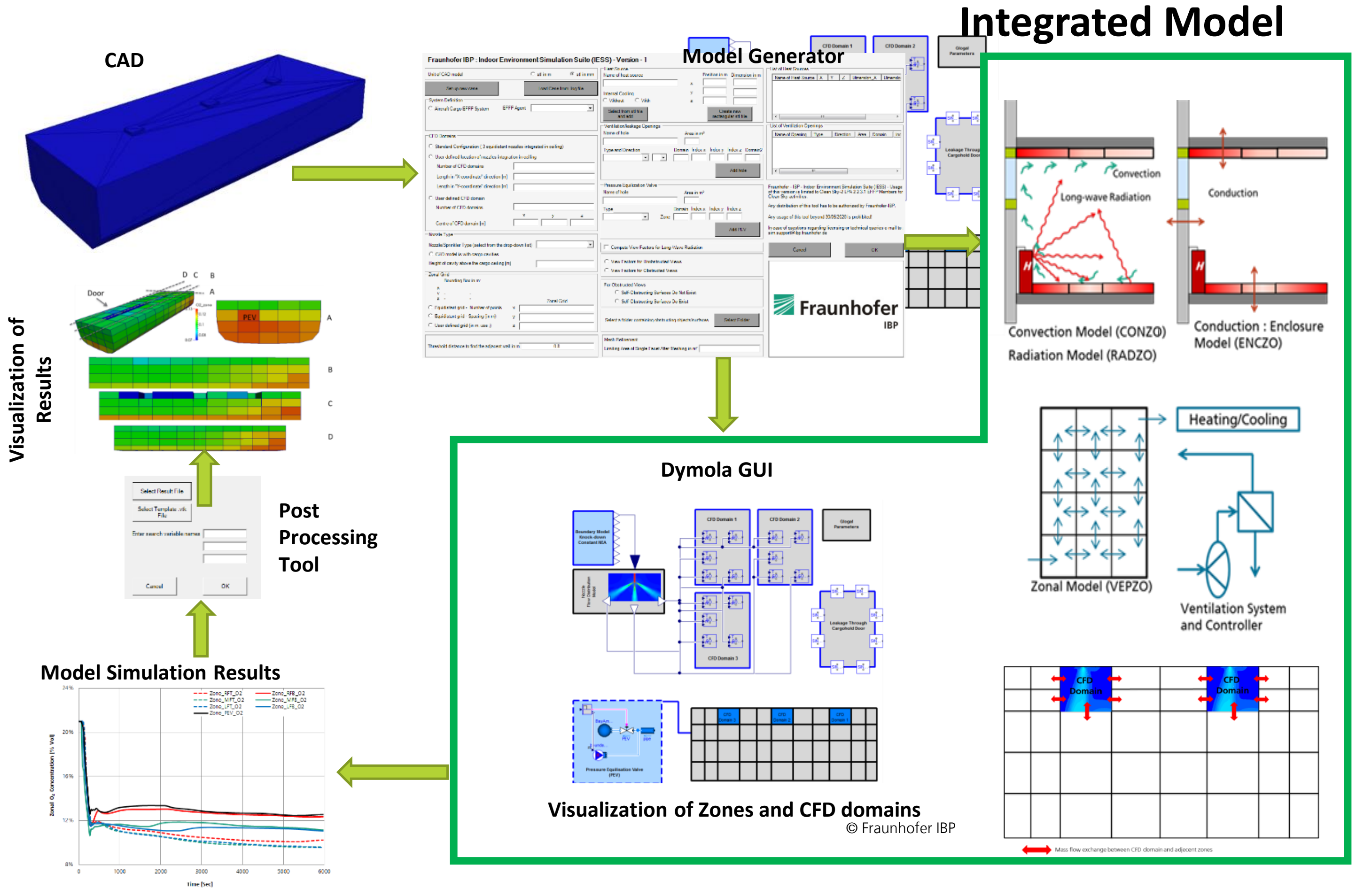
Flow Model

- Links two volume models
- Calculates mass flow rate from pressure difference

Advantages

- Local Resolution
- High simulation speed, transient simulations

Cargo Bay Zonal Model



Radiation
Convection
Conduction

Zonal airflow
Ventilation

CFD domain integration with Zonal model

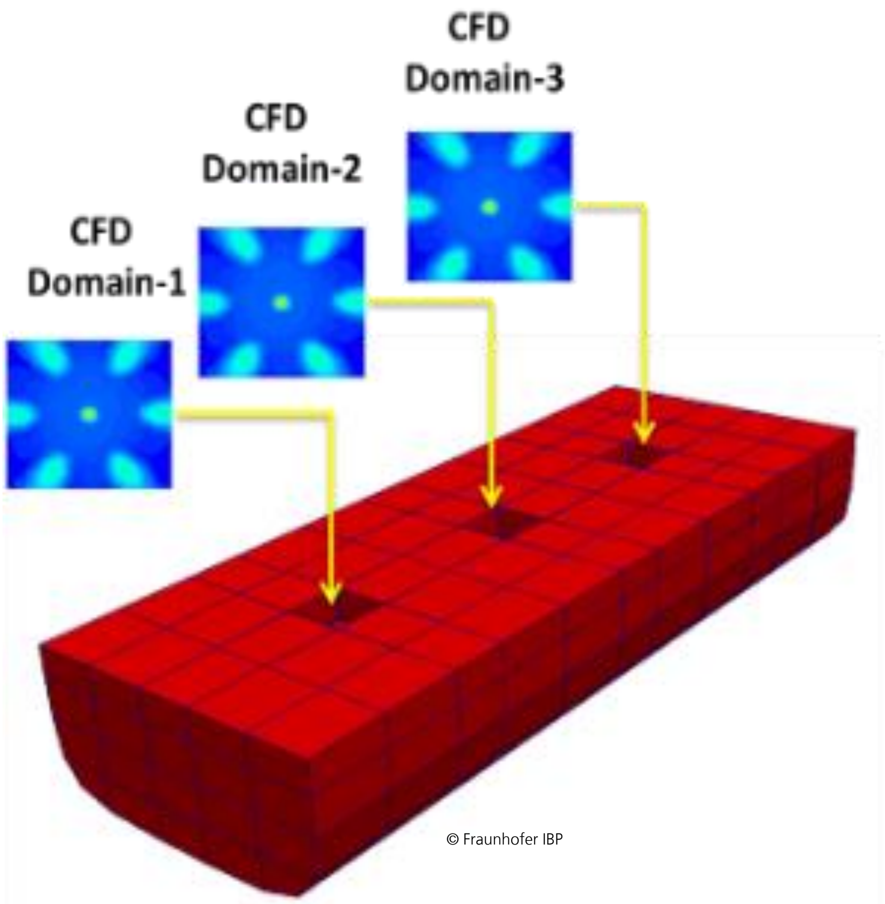
Zonal model integrated with CFD domains

CFD domain

- Simulation of high momentum flow and turbulent eddies in the vicinity of the agent discharge
- Pre-processed CFD domains for each type of nozzle
- Determines the flow of agent in the adjacent zones

Zonal volume – CFD domain interface

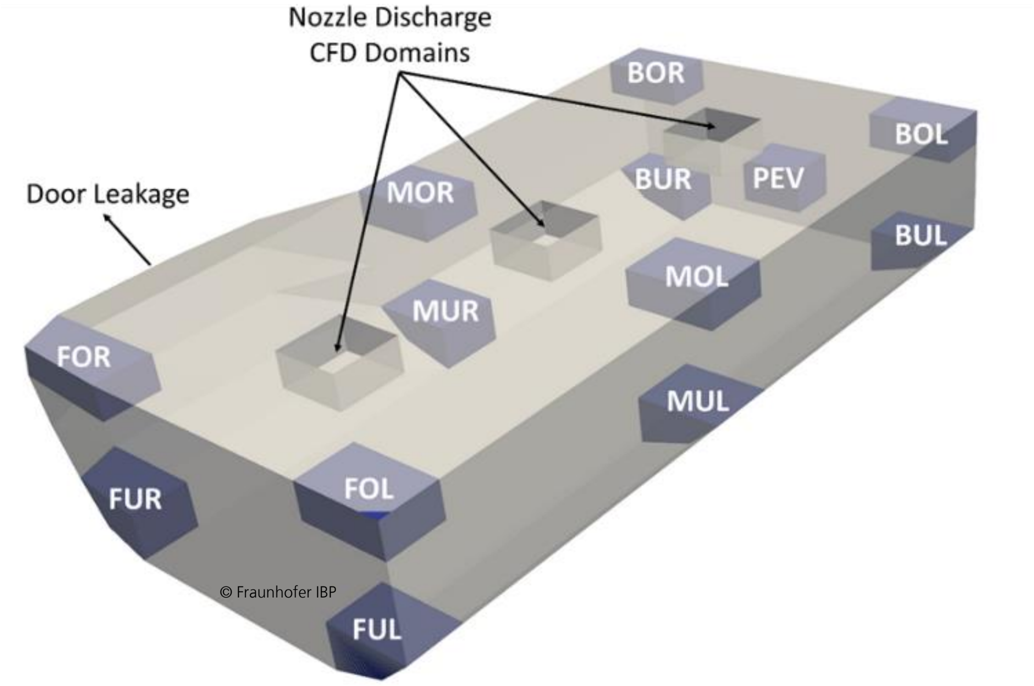
- Mass flow (air and discharged agent)
- Temperature of the mixture
- Agent concentration at the interface



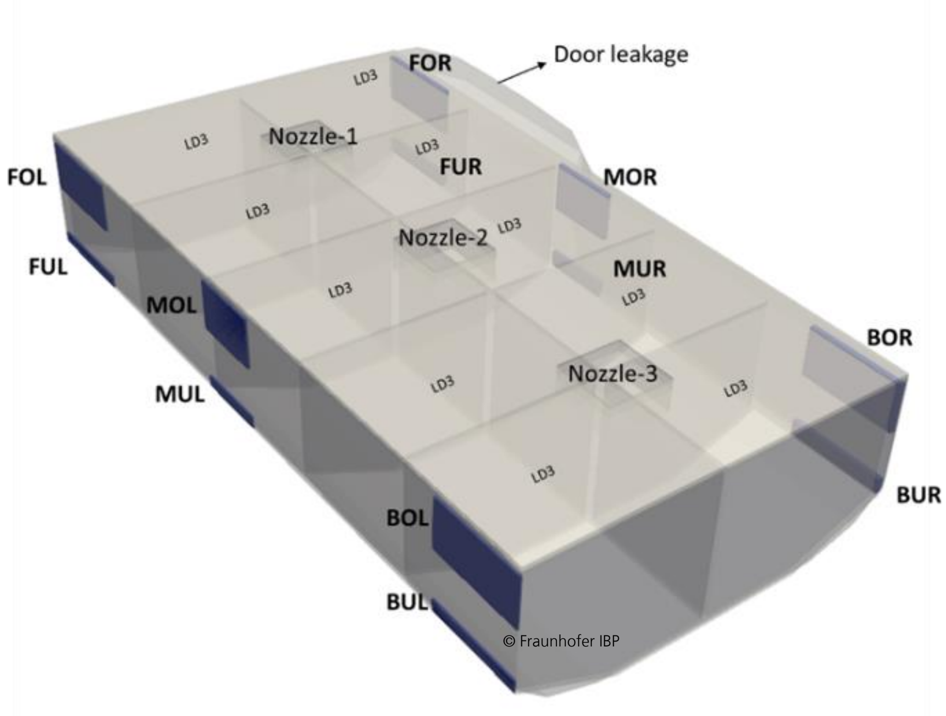
Model Validation

Models for Validation

Empty cargo bay

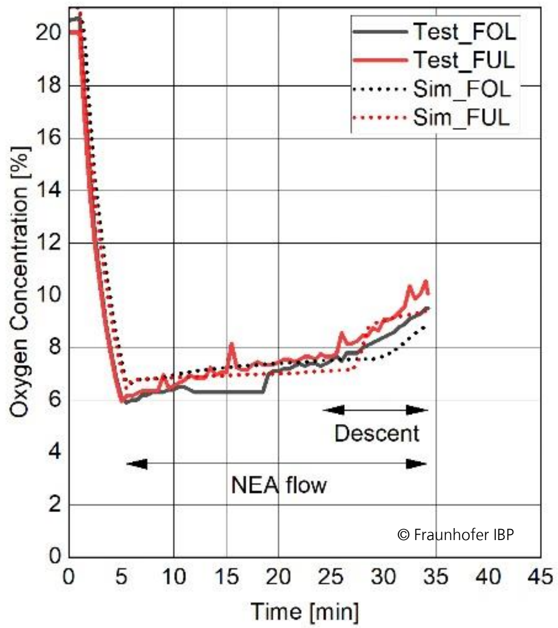


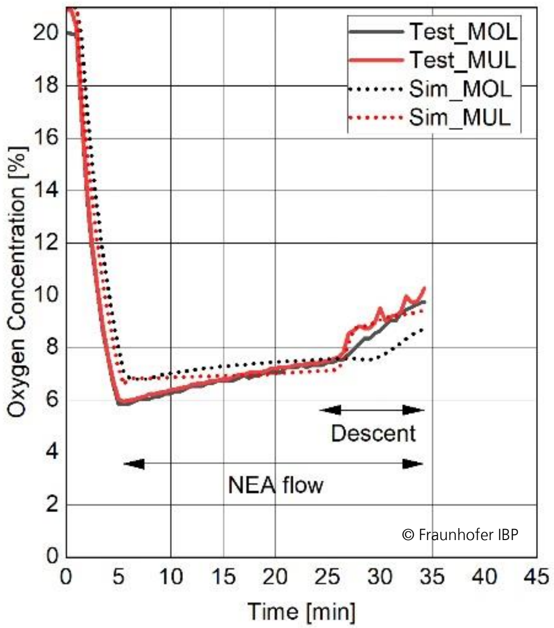
Containerized cargo bay

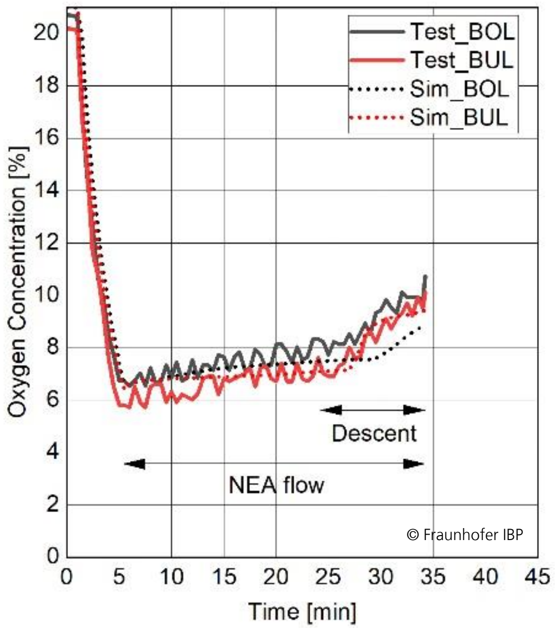


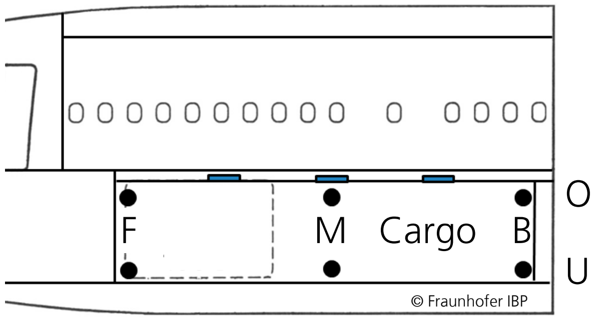
Model Validation – Empty Cargo Hold – Left side

Accuracy of ~1% oxygen concentration









 16.09.2022

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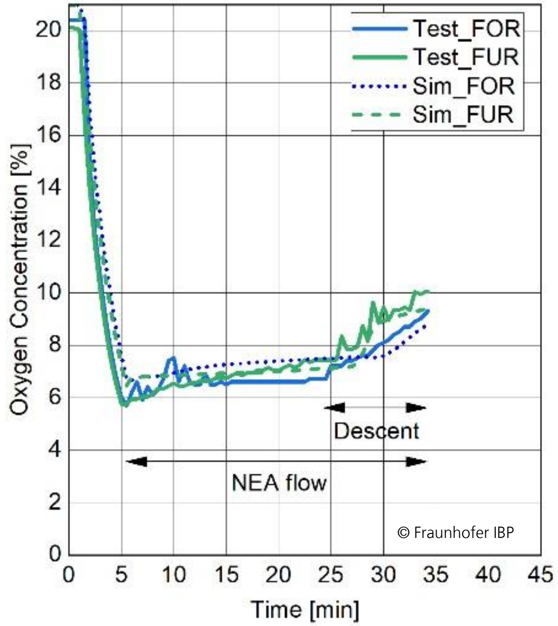
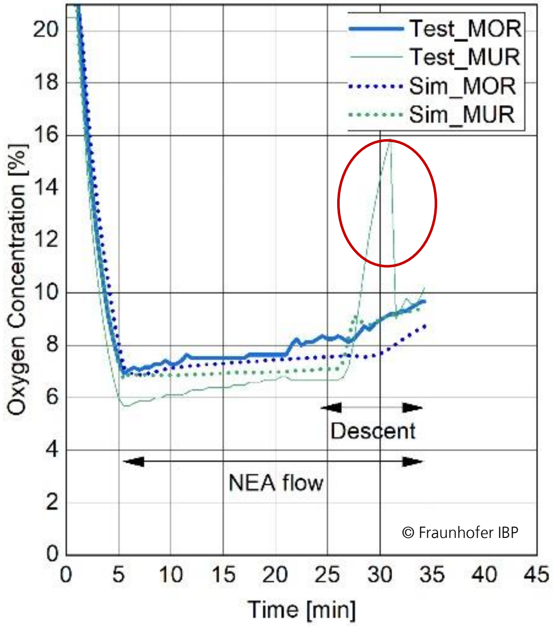
Model Validation – Empty Cargo Hold – Right side

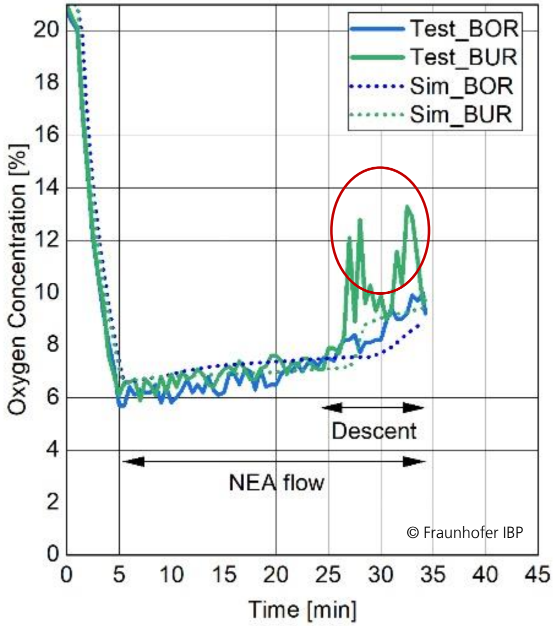
Accuracy of ~1% oxygen concentration

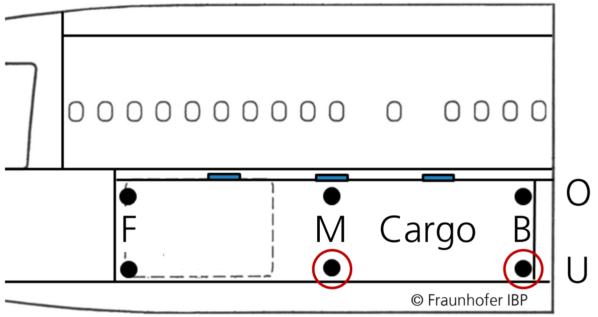
- BOR in descent
- MUR in descent

Sensors probably impacted by local leakages in lining that are not considered in model









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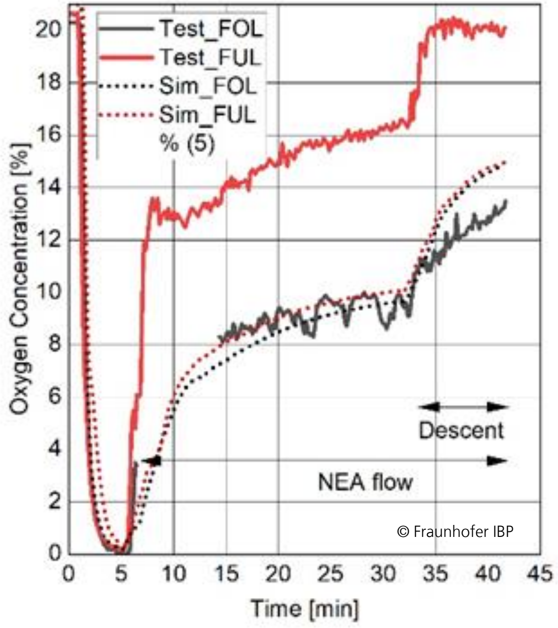
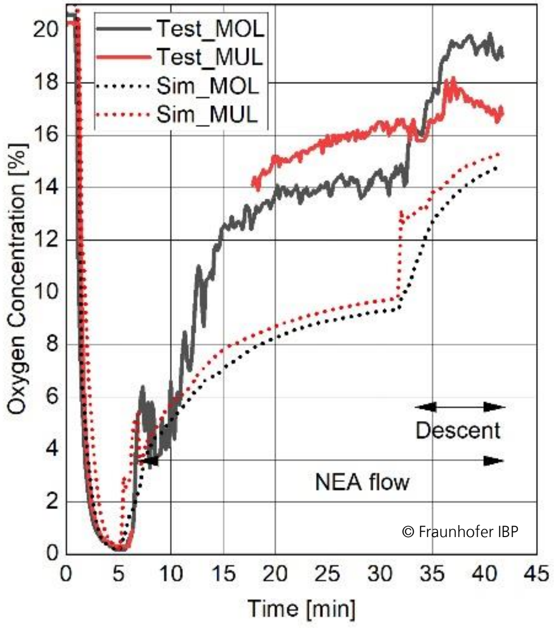
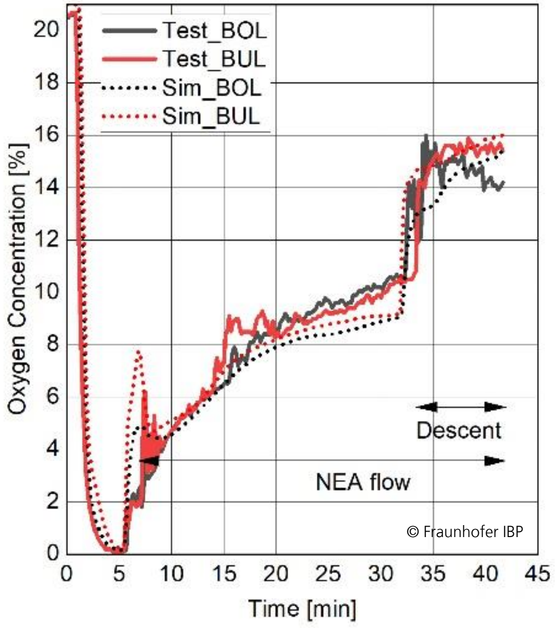
Model Validation – Loaded Cargo Hold – Left side

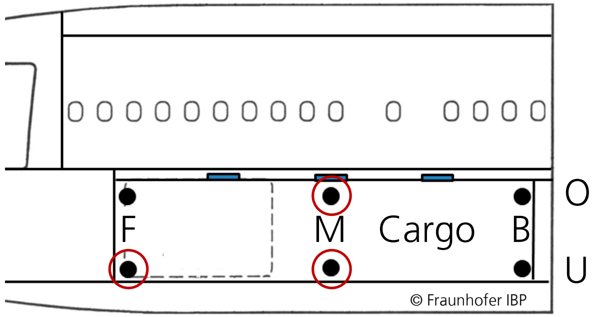
High gradient between measurement positions

- Local leakages act on much smaller air volume
- Model only foresees air ingress at pressure management system









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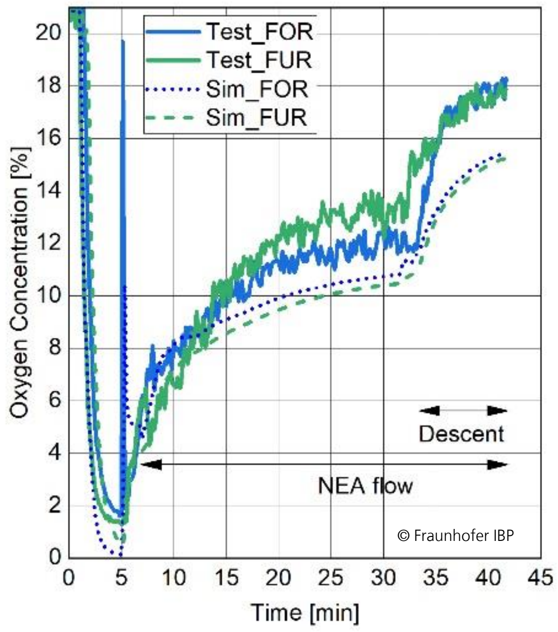
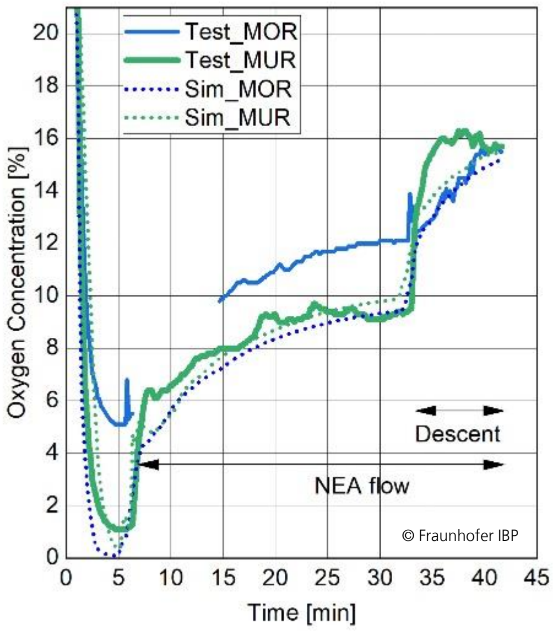
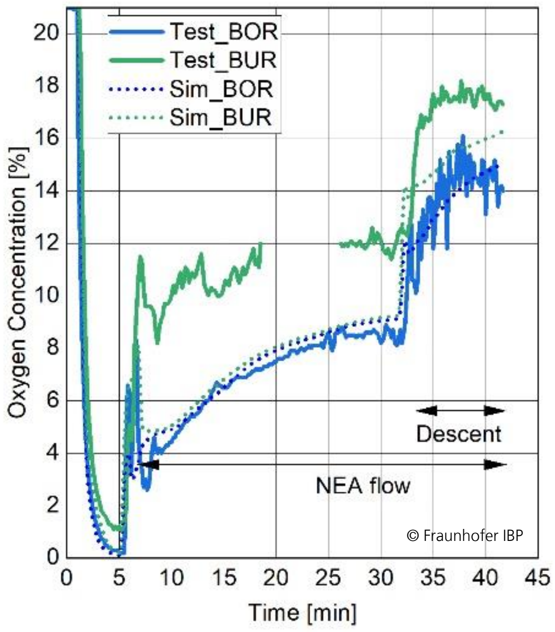
Model Validation – Loaded Cargo Hold – Right side

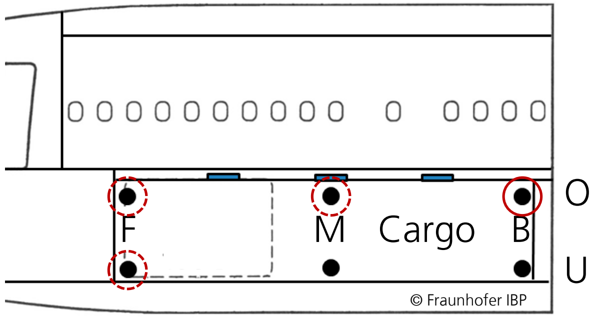
High gradient between measurement positions

- Local leakages act on much smaller air volume
- Model only foresees air ingress at pressure management system





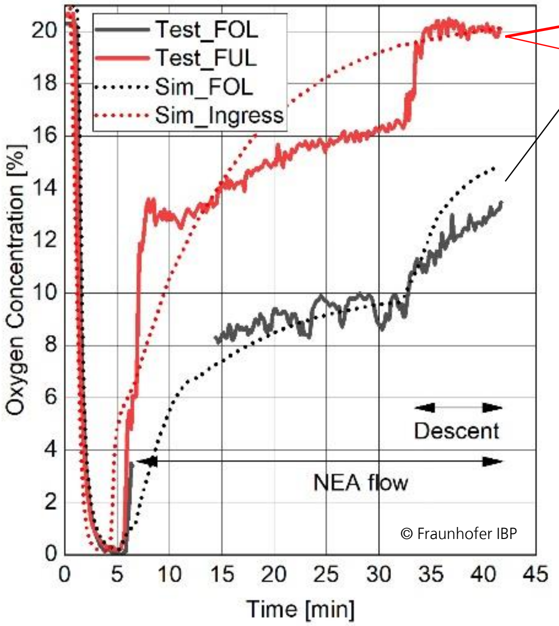




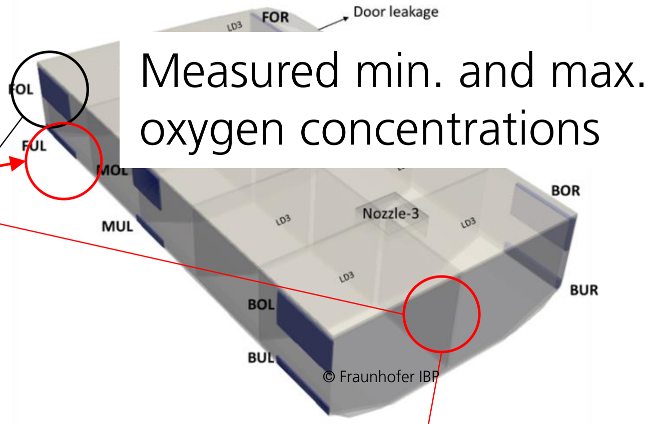
Model Validation – Loaded Cargo Hold
Comparison Min and Max Concentrations

Difference between min and max concentrations reasonably well predicted

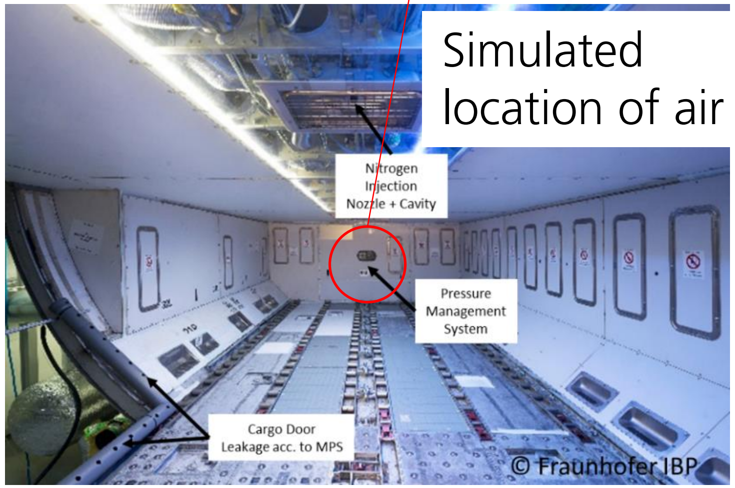
- Exact location difficult to predict due to local leakages in lining
- → Method to detect and eliminate leakages needed



Measured min. and max. oxygen concentrations



Simulated location of air ingress



Cargo Liner Leakage Detection

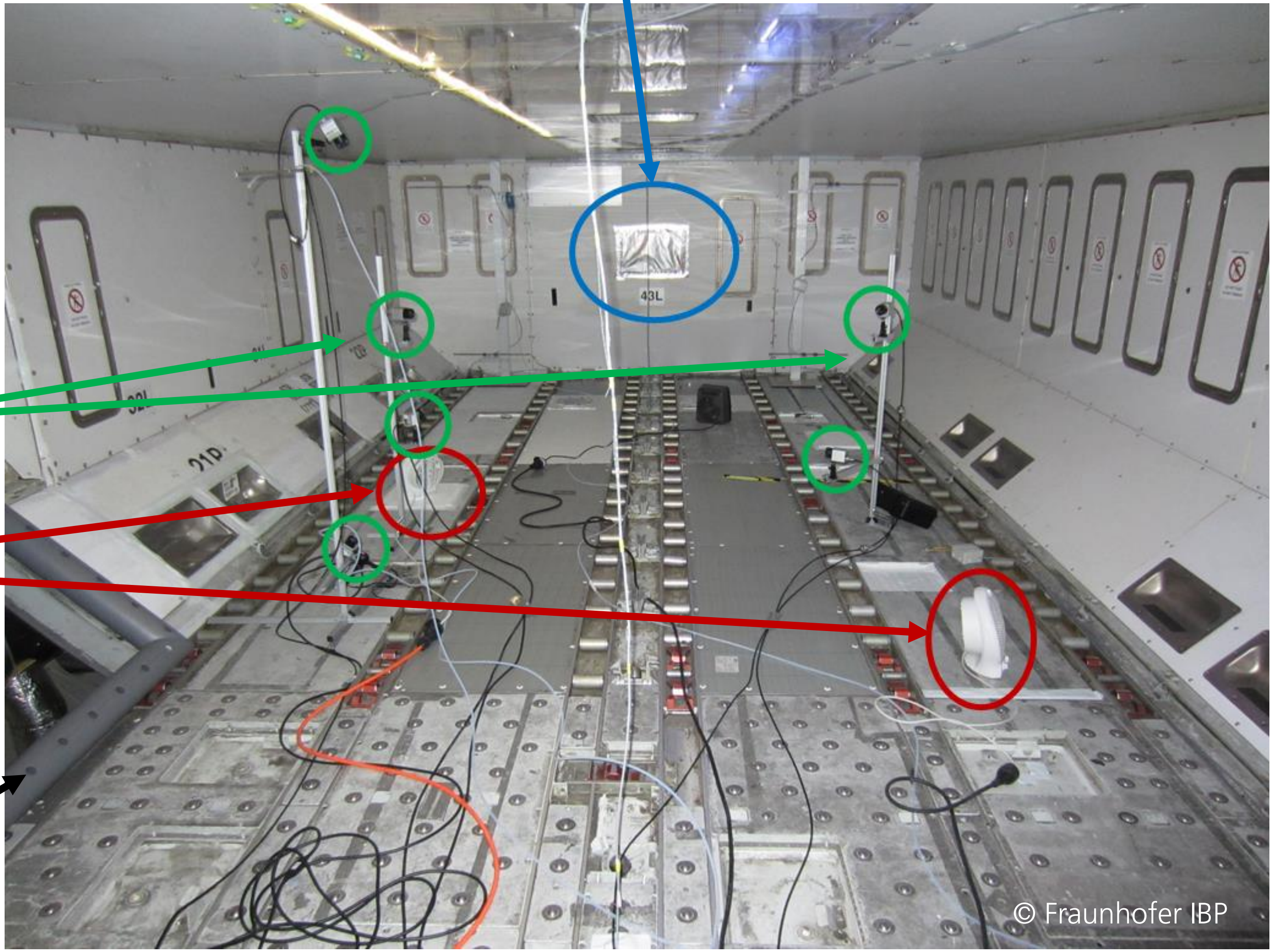
Test setup

Sealed Pressure Management System

IR-Cameras

Heater

MPS conform leakage through cargo door



Test conduct – Cargo Blower Door like test

Step 1: without „Blower Door“

- Cabin ventilation → Cool air flows around cargo
- Heater → Temperature gradient
- After stabilization → Thermography

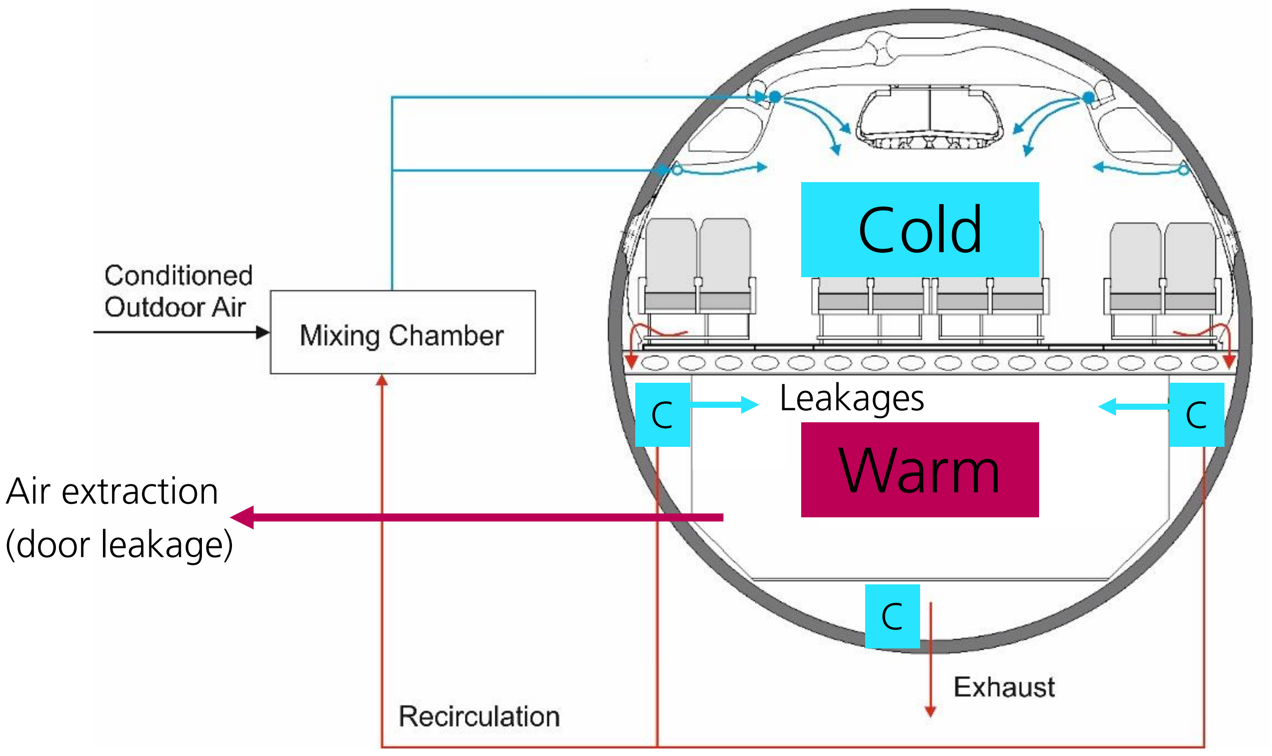
Step 2: with „Blower Door“

- Activation of door leakage as pressure sink
- After stabilization → Thermography

Step 3: Compare thermography from step 1 and 2

- Changed picture → Leakage
- no change → Heat bridge

Step 4: Improvement & Verification

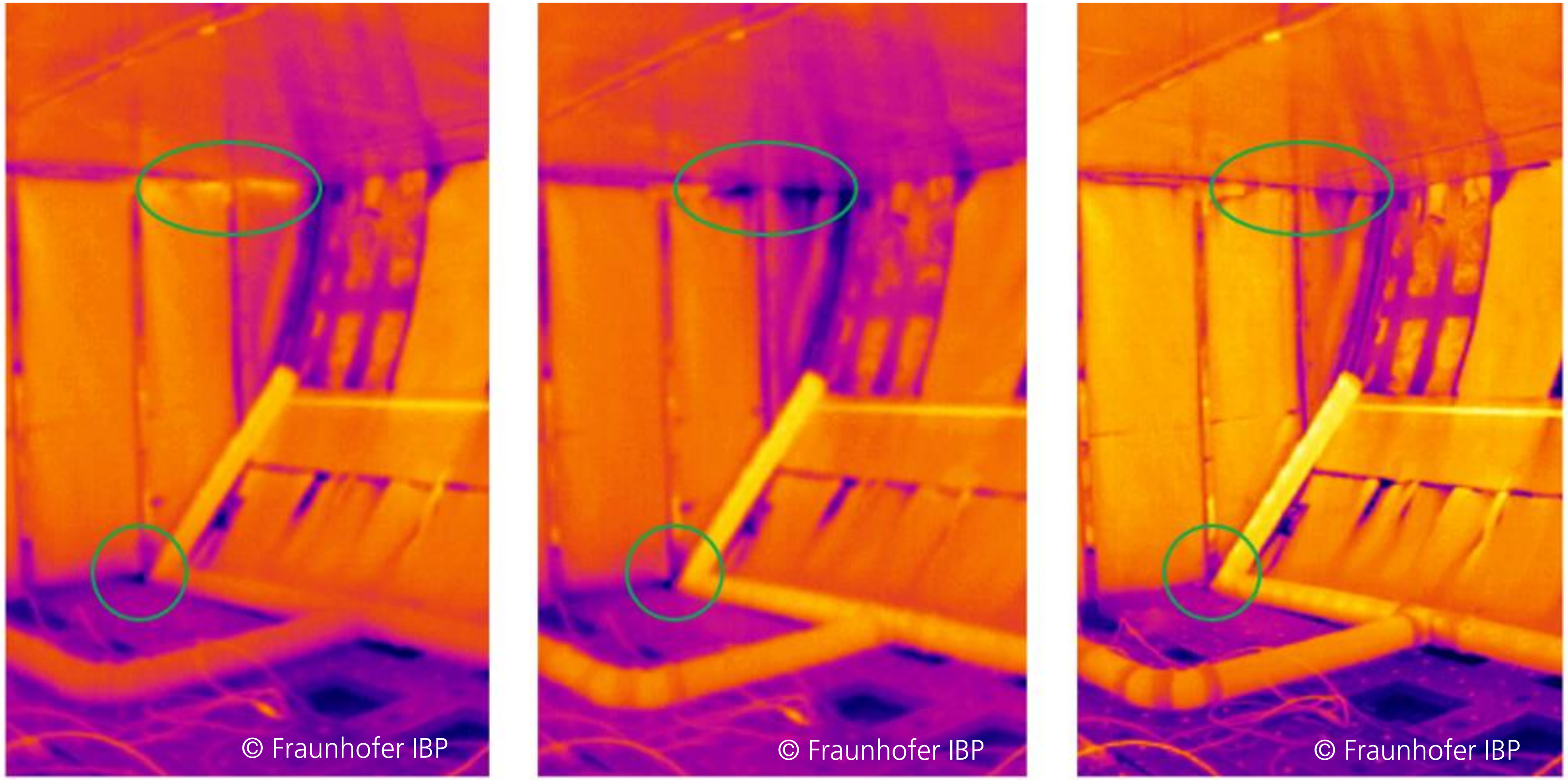


Results – Identified Leakage I

no suction, before sealing | suction, before sealing | suction, after sealing

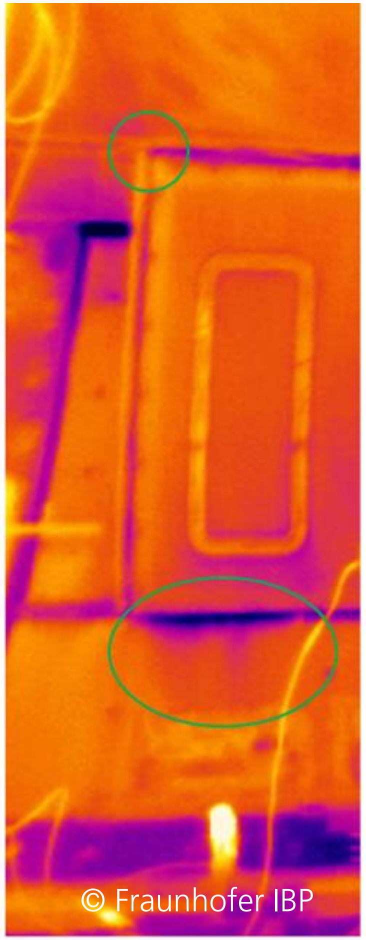
identified leakage

heat bridge

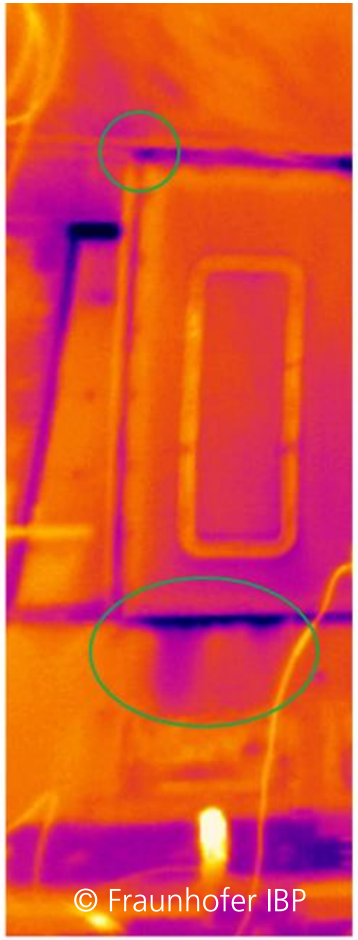


Results – Identified Leakage II

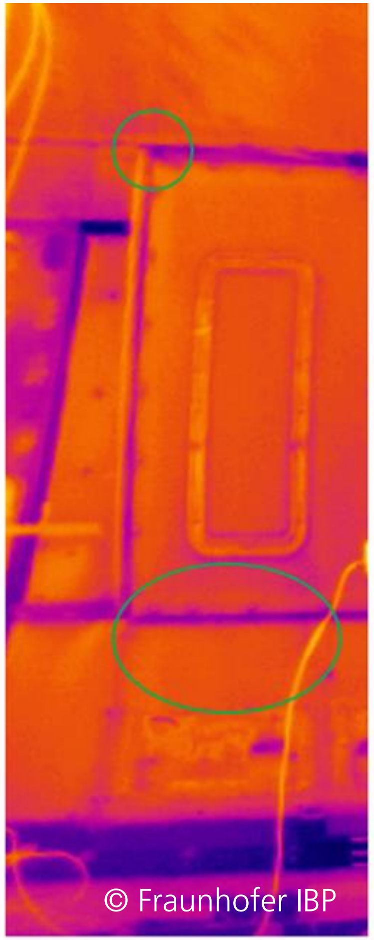
no suction, before sealing



suction, before sealing



suction, after sealing



Passenger Health and Safety

Cabin and Underfloor Ventilation Pattern

Air supply to cabin

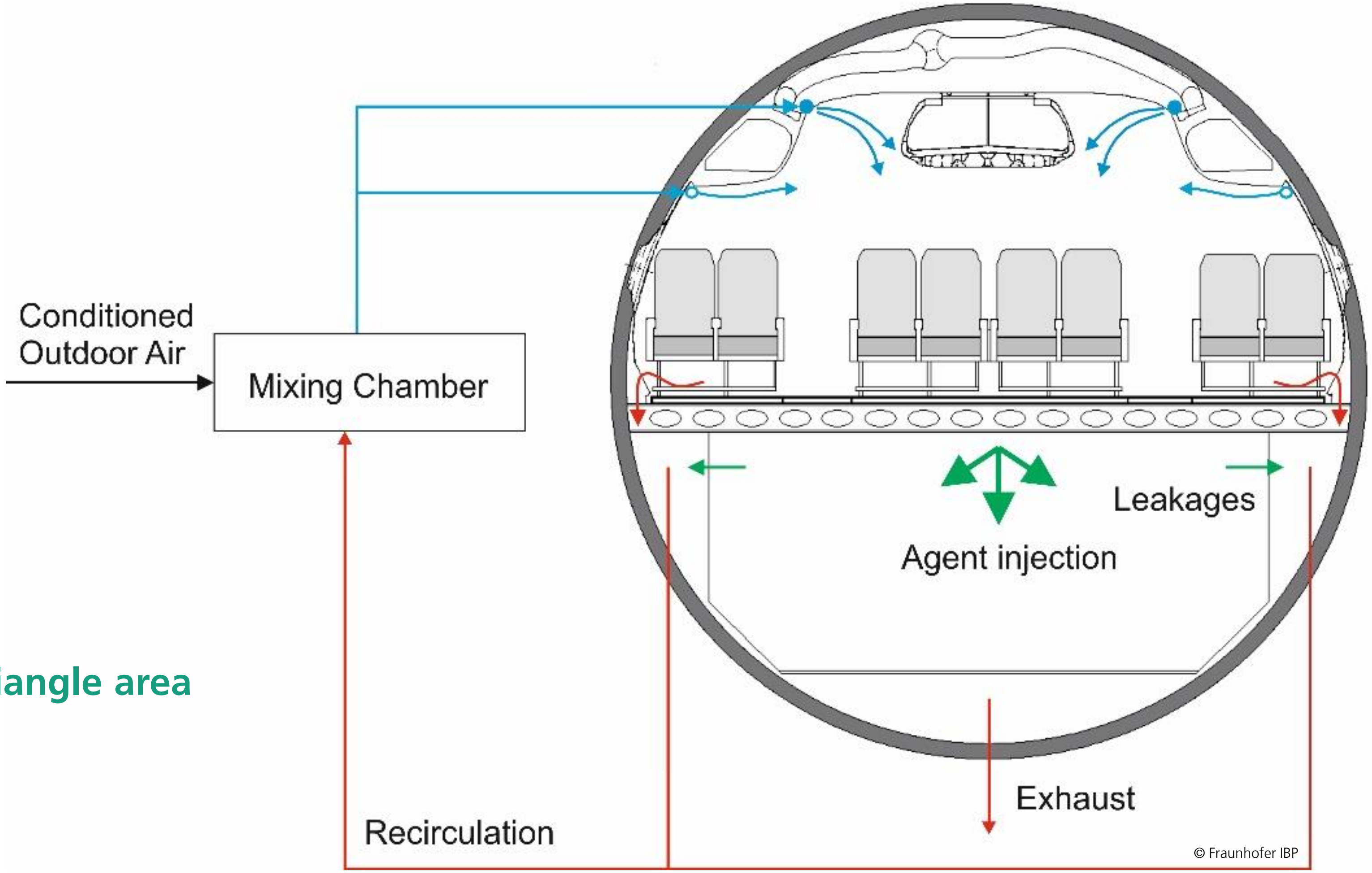
- 50% Fresh
- 50% Recirc, drawn from Triangle Area

→ **Ingress of triangle area air into cabin**

Path for nitrogen to enter cabin

- Leakage in Cargo liners
- Overpressure during knock-down
- Potentially buoyancy forces

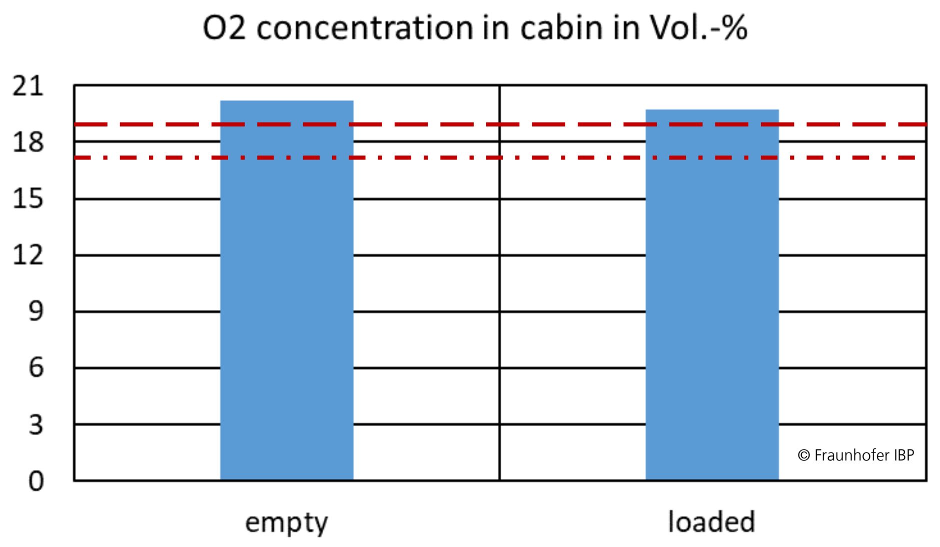
→ **Nitrogen emission from cargo into triangle area**



Passenger Health and Safety Assessment

Full nitrogen discharge

Threshold	Effect	Source
> 19 Vol-%	non noticeable adverse physiological effects	Air Products and Chemicals, Inc.: Dangers of oxygen-deficient Atmospheres, 2014 (36199) 900-13-098-US
≥ 17 Vol-%	Class 0: Employee training, 30min break after 4h work	DGUV Information 205-006: Working in oxygen-reduced atmospheres, November 2013 with issue update from April 2019



→ No adverse reduction of oxygen concentration measured in cabin

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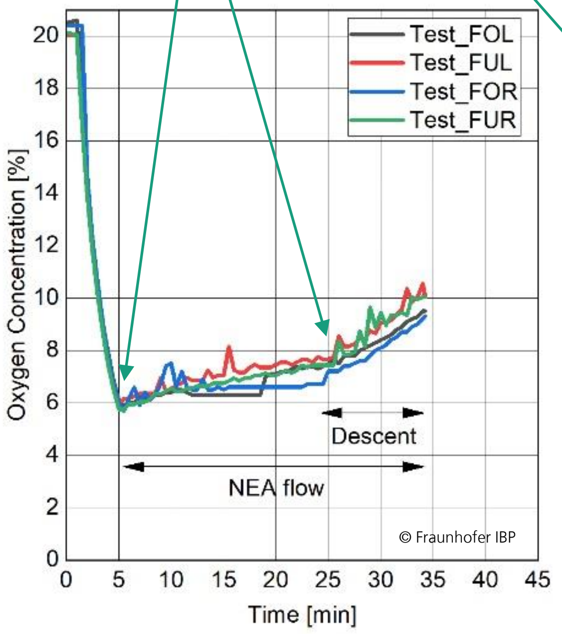
Conclusion

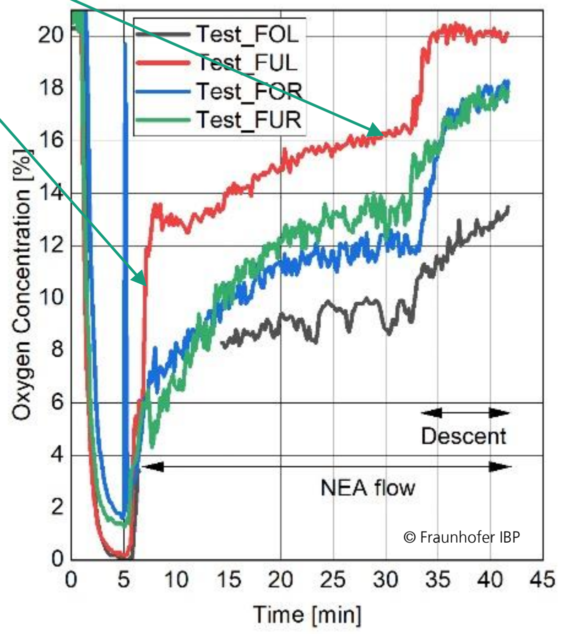
Conclusions

Comparison Empty vs. Containerized load

- Different dynamic response at start of NEA flow and start of descent

empty





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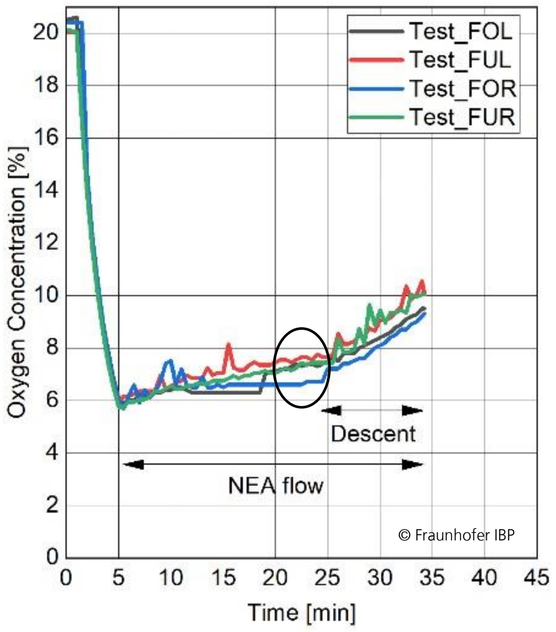
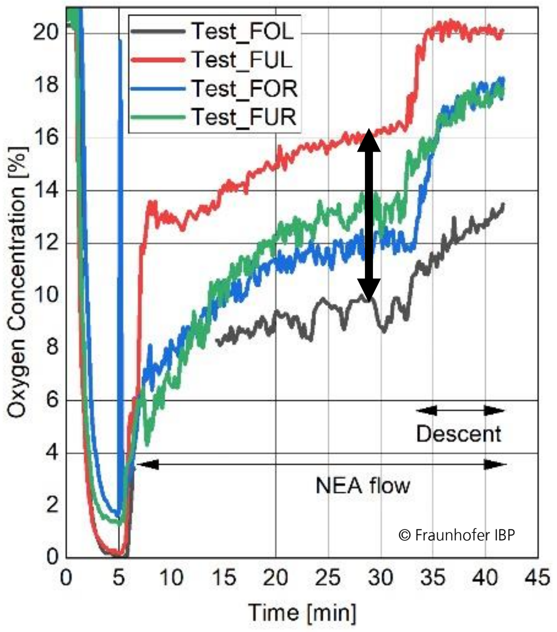
Conclusions

Comparison Empty vs. Containerized load

- Different dynamic response at start of NEA flow and start of descent
- Different local gradients in cargo hold

empty





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Conclusions

Empty Cargo Hold

- Good prediction of transient oxygen concentration profile
- Local leakages show lower impact on measurements

Containerized Cargo Hold

- Min. and Max. transient oxygen concentration reasonably predicted
- Local deviations due to huge impact of lining leakage distribution
- Leakage pattern non-predictable, lining installed as airtight as possible

Blower Door method for Leakage detection

Passenger Health and Safety Assessment shows no issues in cabin

Outview & Acknowledgement

Upcoming presentation with N_2-bottles with higher TRL

Extension of test rig and simulation method to

- High-boiling point agents
- Two-phase flow conditions

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