SIMULATION BASED LANDING SYSTEM VERIFICATION - ABOUT THE CHALLENGES OF NON- LINEAR ERROR ESTIMATION

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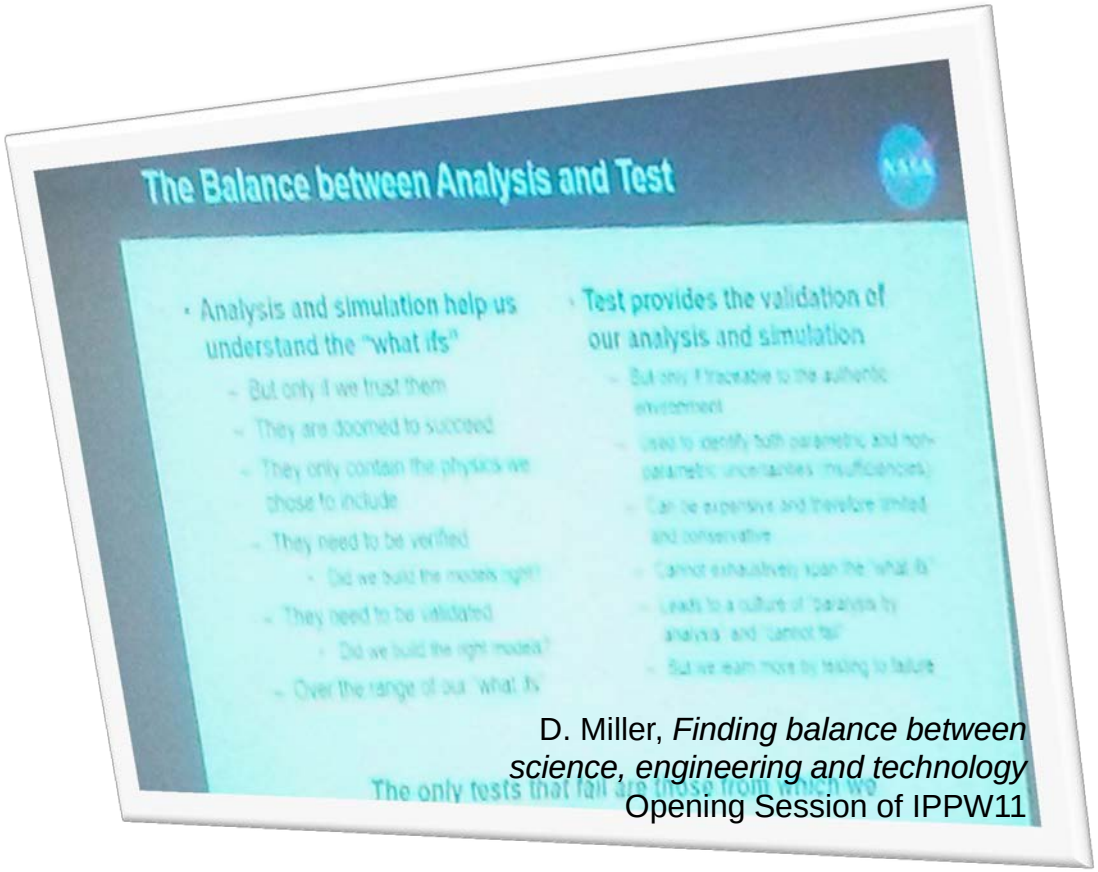
AIRBUS DEFENCE & SPACE

DLR

Intro

- **Simulation based verification**
  too risky?
  too immature?
  so - why at all?



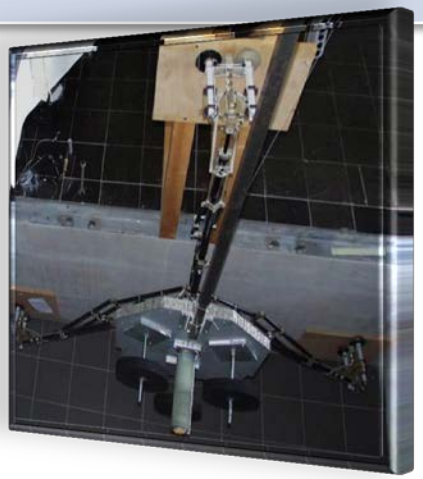
D. Miller, *Finding balance between science, engineering and technology*
Opening Session of IPPW11

- **Bottom up model correlation and validation - How do we generate trust in the results when we cannot reproduce the operational environment of the target planet on Earth?**

- **Challenges when facing non linear sensitivities - Be aware that the results might not be as expected!**

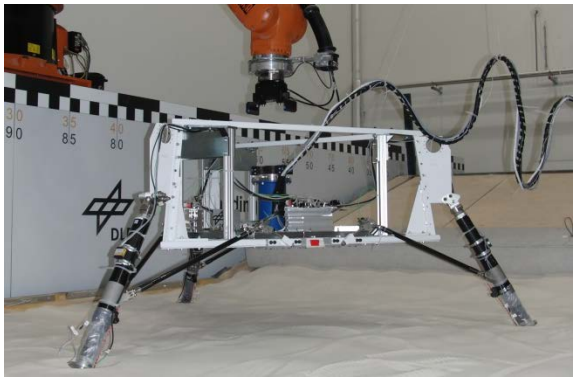
Methods for the verification of landing dynamics

Concept	Pendulum tests	Scaled free fall tests	Active weight off-loading
Description	The test object is guided by a dedicated suspension device. Against an inclined plane. The acceleration in this direction can be adjusted by the inclination angle.	Scaling of test objects to get similar dynamical behavior under 1g compared to the full scale lander under the gravitational environment of the target body (laws of similarity).	Difference in weight between target body and laboratory environment is actively compensated (off-loaded) by a robotic device.
Advantages	- (Full) scale tests possible - No weight limitation	- 3D motions without additional constraints - Testing on soil simulants possible	- 3D motions without additional constraints - Testing on soil simulants possible
Disadvantages	- Additional support - Only 2D cases - No tests on soft soil / regolith	- Excessive miniaturization for target bodies with very low gravity	- Interaction between the test object and the robot (mechanical low pass filter) - Quality depends on controller performance



Simulation based verification based on free fall tests

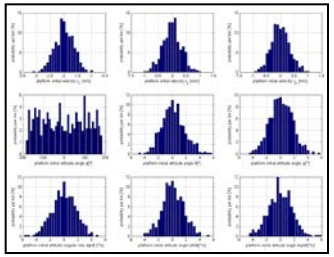
Realization of several terrestrial demonstrators:



→Uncertainty factor of >1.25 to cover the missing system correlation

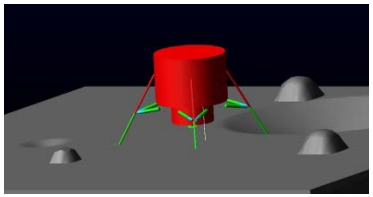
Example: ESA Lunar Lander

Touchdown parameter



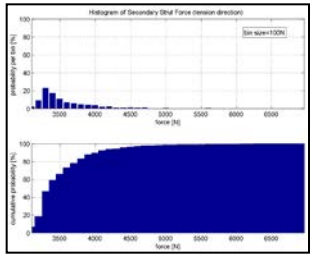
Statistical variation of input functions

Virtual test bed A³LDS v1.0



Statistical representation of landing site candidates

History + peak monitoring



Statistical analyses of output functions

Landing System Spec.

Units	99.80%
[N]	-4416
[N]	6957
[mm]	-102
[mm]	81
[N]	7500
[N]	-1536
[mm]	-195

Definition of design loads and ranges

Design verification by single leg analyses and tests regarding Monte Carlo landing loads and functional design ranges (3σ multiplied by an uncertainty factor of 1.25)

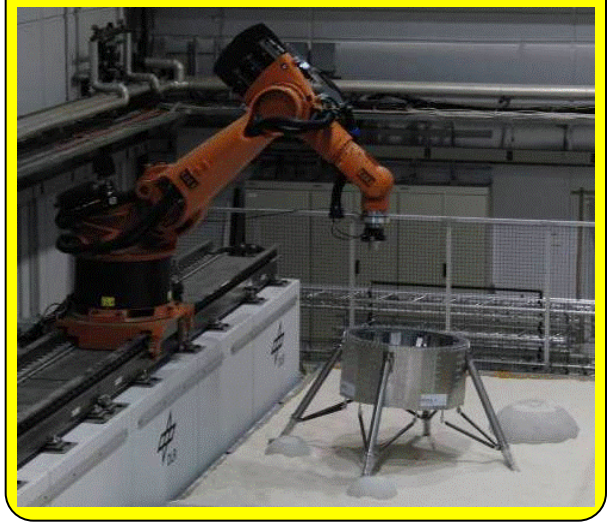
Assumption: Uncertainty is similar to the later flight application!!!

Bottom up V&V approach

Can be used for model correlation

Can only be used for model correlation if all relevant elements are scalable

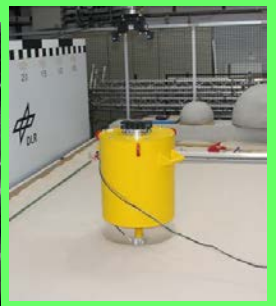
- LEM drop tests



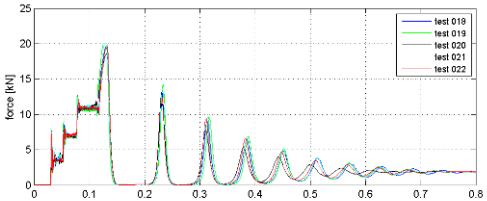
- **Material characterization**
  - Strain rate coefficients
  - Temperature effects

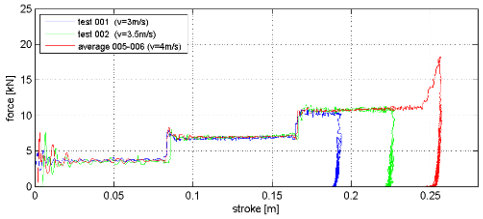
- **Assembly verification**
  - Footpad to soil interaction
  - Load Limiter hysteresis
  - Main damper hysteresis
  - Bearing friction

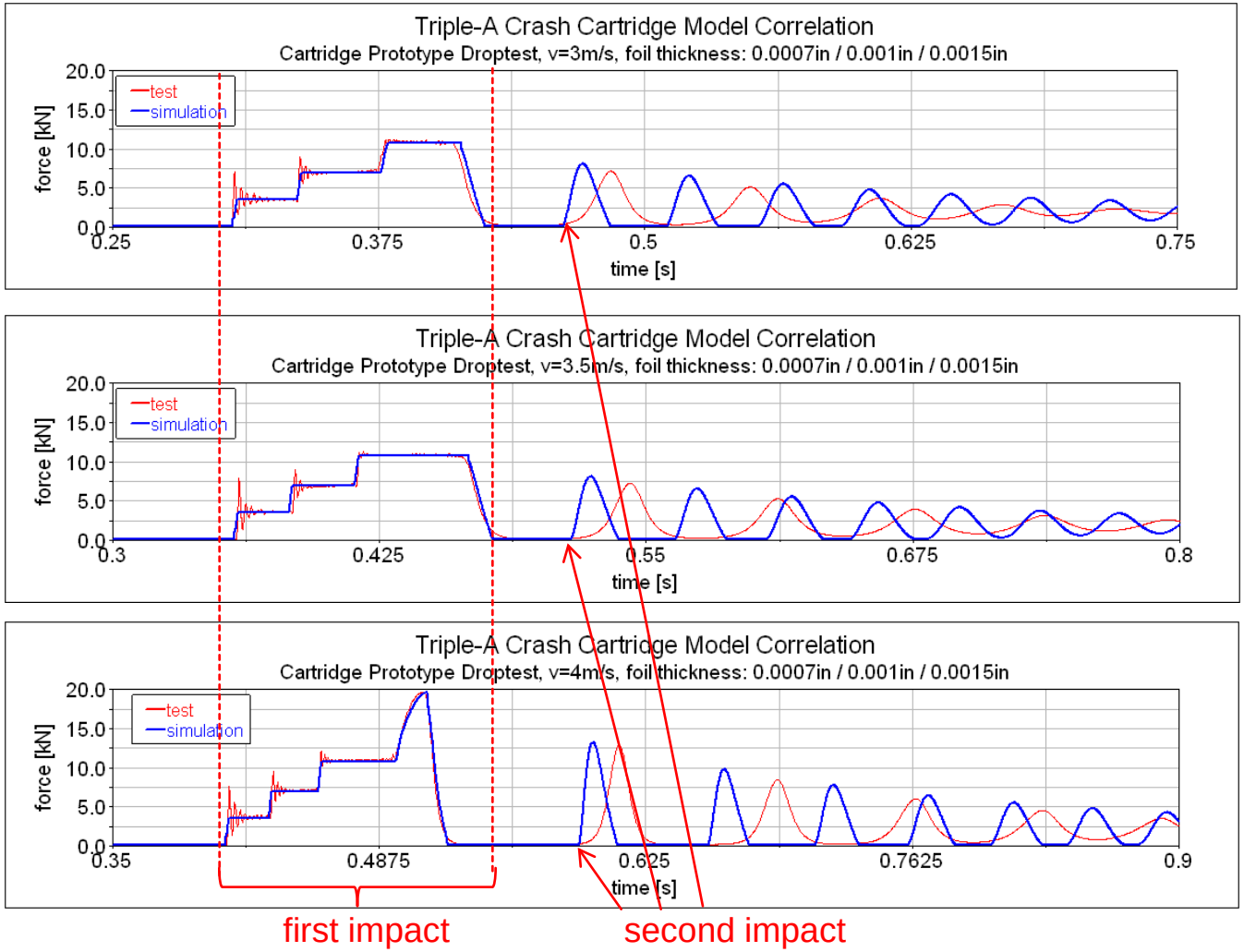
- **Single leg tests**
  - Inclination angle
  - Reduced mass
  - Impact velocity



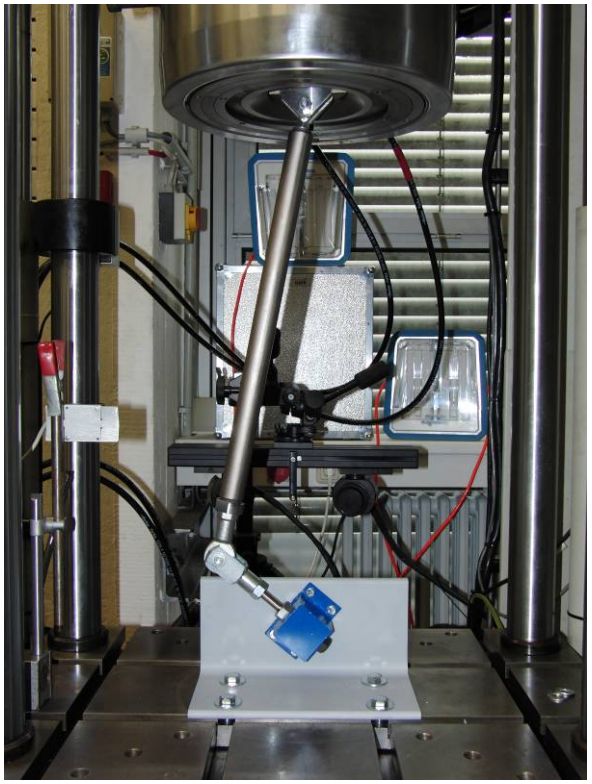
Main damper model correlation

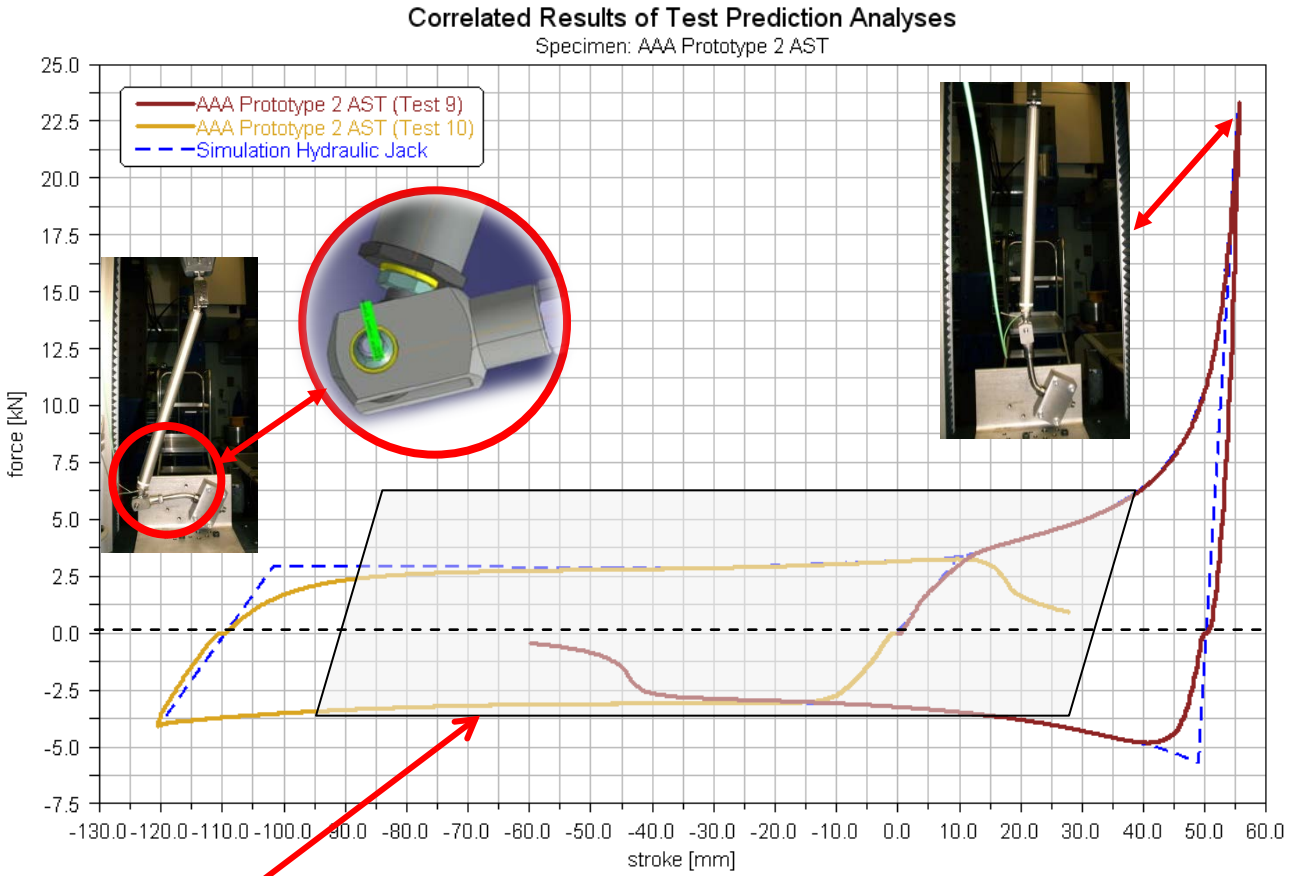






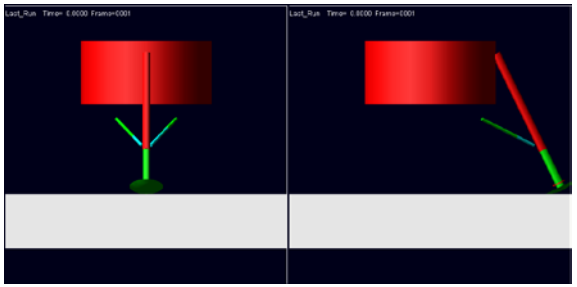
Load Limiter model correlation



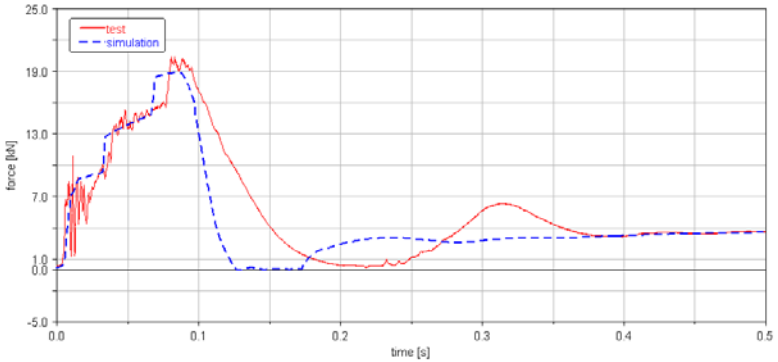


comfortable design range

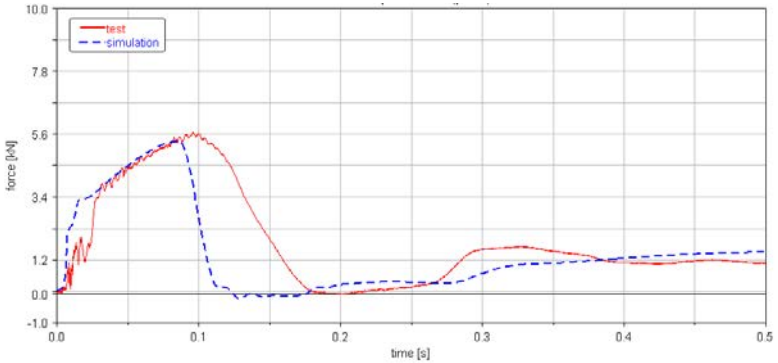
Single leg model correlation



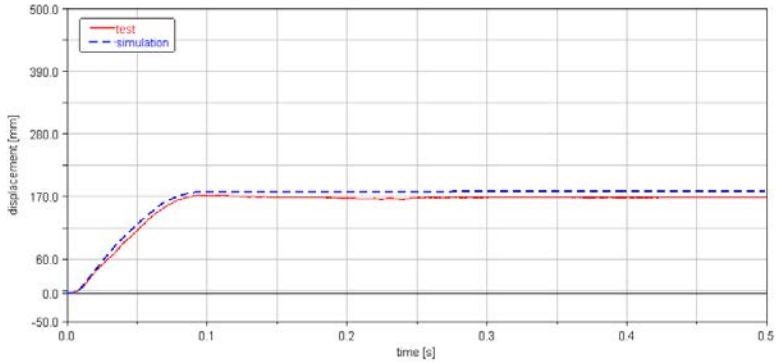
Primary strut upper joint force



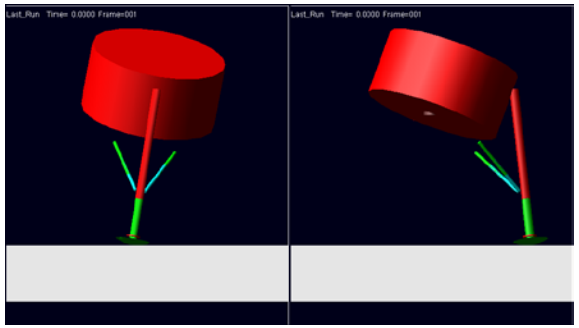
Secondary strut force



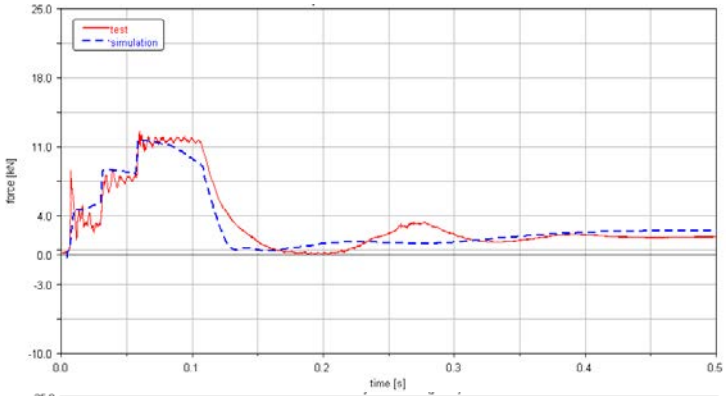
Main damper stroke



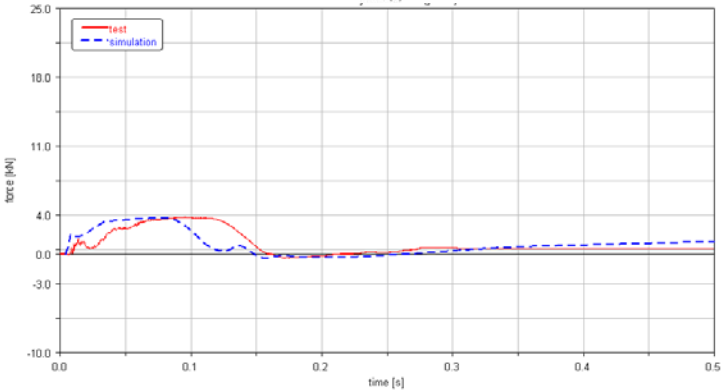
Single leg model validation



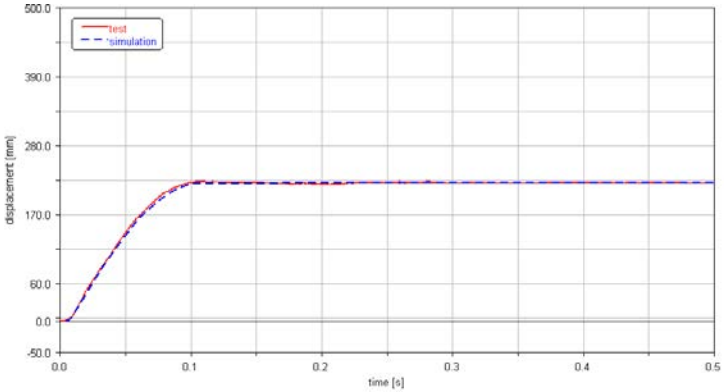
Primary strut upper joint force



Secondary strut force

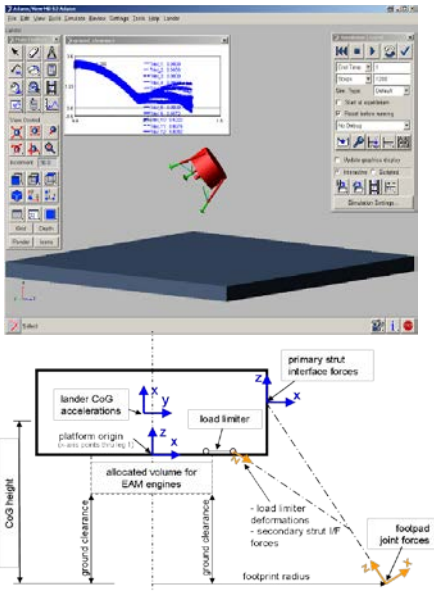


Main damper stroke

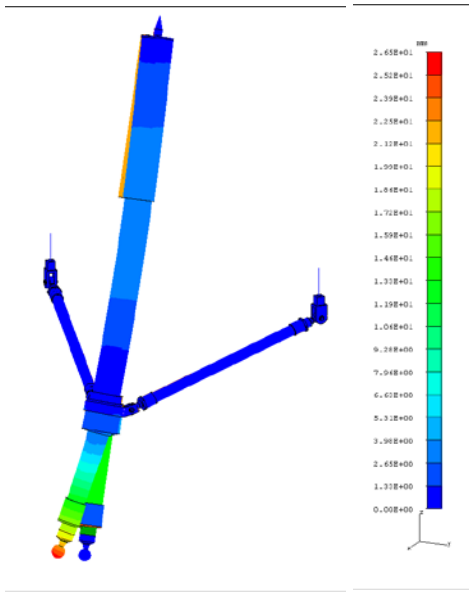


Application of the V&V approach to the Hover Maneuver Demonstrator *HOMER*

Step 1: DoE based design load definition



Step 2: Static design verification using FE tools



Step 3: EQM single leg drop test

Step 4: flight test

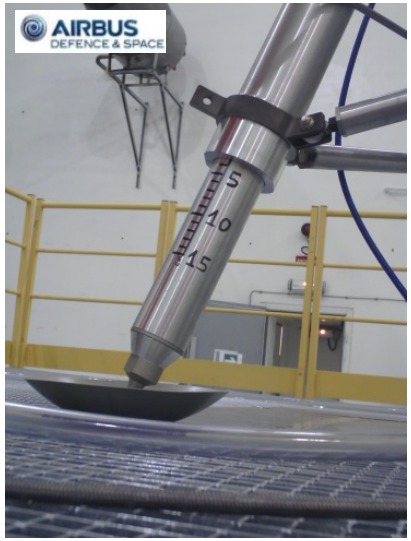
source: www.astrium.eads.net,18.06.2013

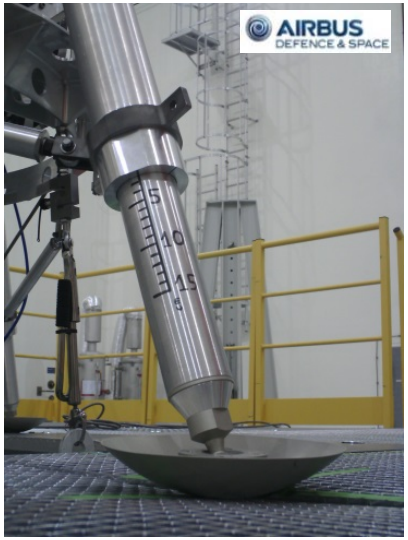
Requirements / Objectives for the landing system:

- Shock attenuation to enable a second test after a landing under nominal conditions (1.5m/s)
- System safety to enable a second test after a small recovery time in case of emergency landing (7m/s)
- Design to be representative to demonstrate TRL 4-5

Flight test and post flight analyses *HOMER*

load limiter	DOE	h	vv0	cartridge stroke	cartridge force	load limiter stroke		load limiter force		platform I/F force z	
		[m]	[m/s]	[mm]	[N]	[m]		[N]		[N]	
		max	max	max	max	min	max	min	max	min	max
HMR-Prototype 2b	v9_002	0.00	1.5	11.5	5500	-0.004	0.023	-2130.6	3325.4	-2599.8	8386.2
HMR-Prototype 2b	v9_003	1.50	1.5	176.5	14850	-0.105	0.099	-5640.8	16085.5	-5366.7	20785.7





Post flight analyses after nominal landing:

- Main damper deformations greater than predicted:
  Prediction: 11.5mm;
  Test: between 25and 30mm
- Load Limiter deformation smaller than predicted:
  Prediction: 23mm
  Test: approx. 15mm

Probable cause of the deviation:
Stiction effects on the gratings are not covered sufficiently in the applied Coulombs friction model.

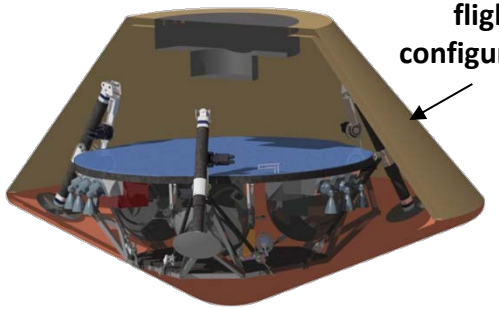
Application of the V&V approach to the Triple-A Lander

Reference mission

- Reference scenario based on ESA Mars Precision Lander (MPL)
- Delivery of a 85kg “Sample Fetch Rover” to the surface of Mars

Concept

- Engine cut-off at physical contact using a failsafe electro-mechanical ground contact sensor attached to the footpad joints
- Landing shock attenuation using light weight landing legs with incorporated crushable Aluminum honeycomb shock absorbers
- Lowering, lifting and leveling of the platform using a robotic leg deployment arm with two active rotary joints
- Adaptive path planning based on on-board sensor data



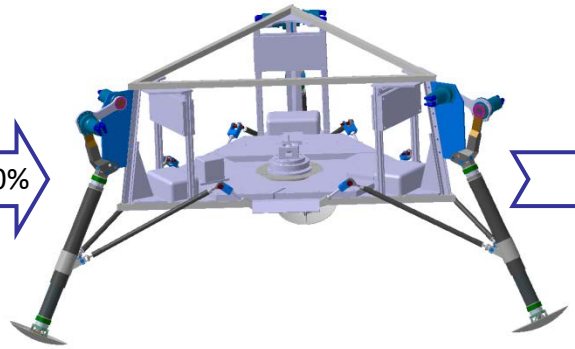
Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag

support codes:
Triple A 50 RA 1030
Triple-A follow on 50 RA 1321

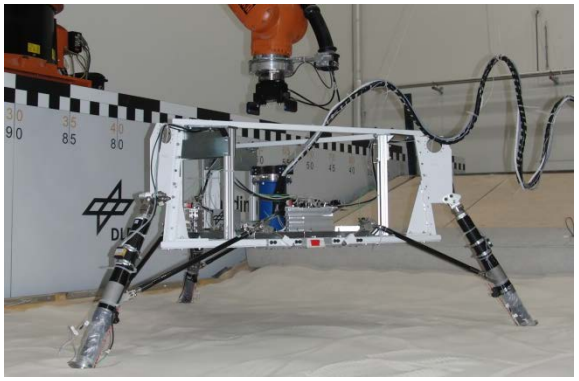
Triple-A Robotic Lander

≈ 100%

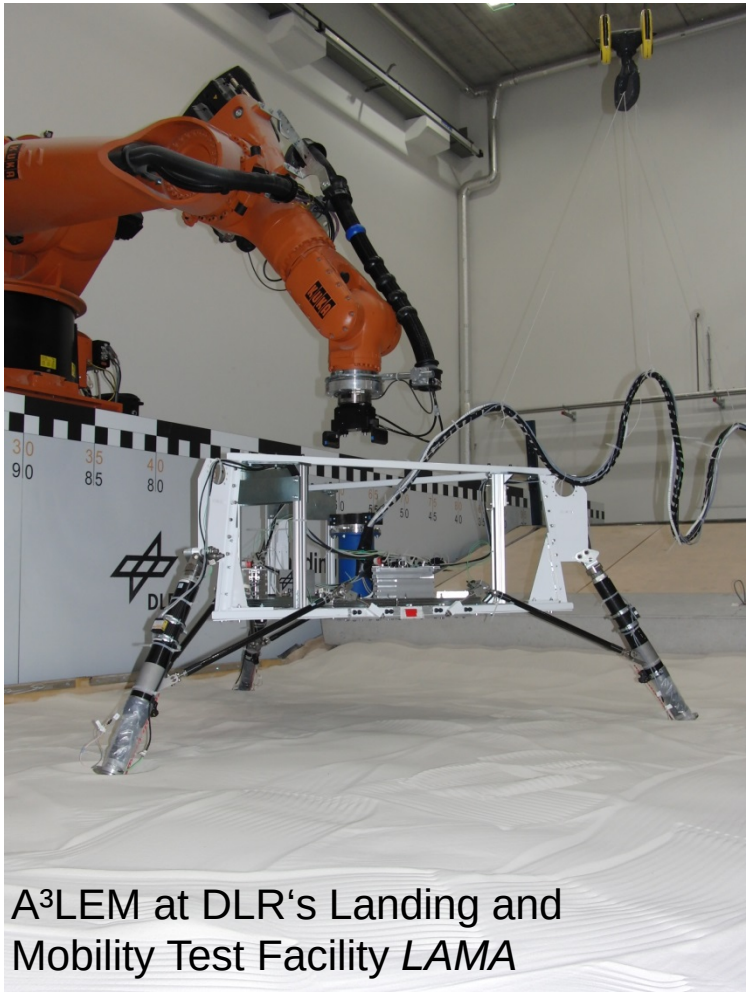
Demonstrator Layout



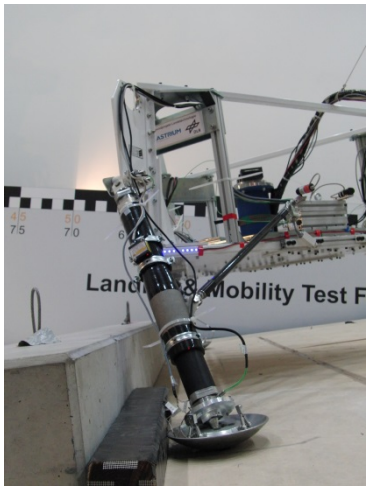
A³LEM Hardware

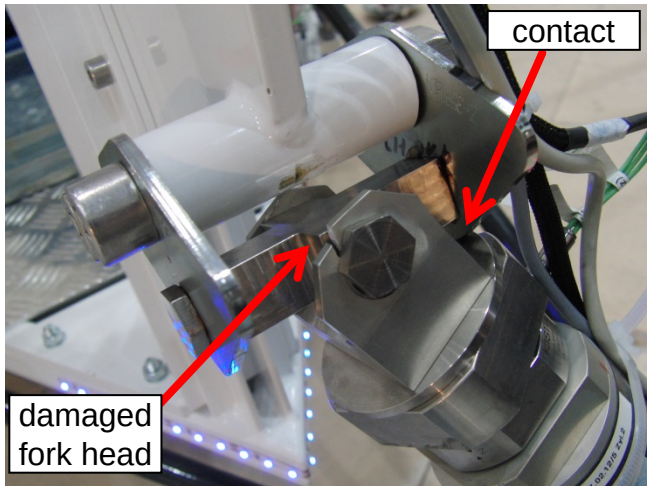


Drop tests and post test analyses *A³LEM*



A³LEM at DLR's Landing and Mobility Test Facility *LAMA*





Post flight analyses after roll over of the platform:

- Contact between force transducer washer and platform
- This contact was not modelled!!!

→ Lateral impedance much higher than predicted

→ Roll over / loss of mission

Conclusions:

- We have to absolutely sure that all relevant effects are implemented in the model
- Such effects can only be detected by tests

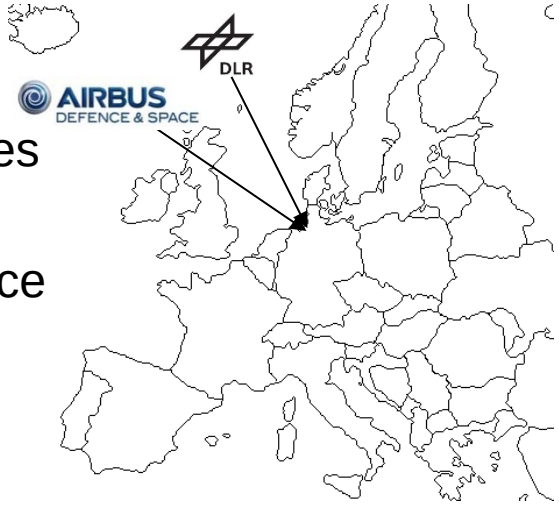
Conclusions / Statements

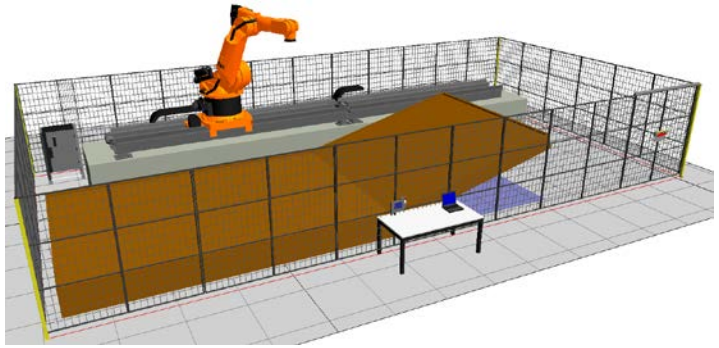
- The decision for simulation based verification methods is not necessarily driven by the costs. Sometimes, we simply don‘t have an option.
- Special focus has to be set on the validation of the numerical models. We need to be sure that we understand our model and the results properly.
- Validation requires a high number of tests on a low level of integration, a smart choice of the setups and lots of discipline.
- Non-linear effects can have an unexpected impact on the results. System tests are required to make sure that all relevant effects are included in the model.
- The correlation on system level is sometimes not possible due to the missing *“real world data”.* An additional uncertainty factor has to be introduced to make sure that we are on the safe side.
- Do we really want to apply the same standards as for launchers or satellites? What level of risk is acceptable for exploring new frontiers?

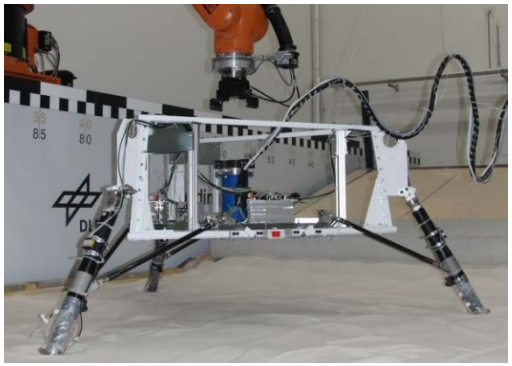
Backup: Joint Co-Operative Team “Landing Technology“

Background:

- Goal: Joint investigation and validation of new methodologies for the verification of landing systems
- Team: Working group members from DLR‘s Institute of Space Systems and Airbus Defence & Space in Bremen
- Programmatic: MoU / No exchange of funds







- Landing and Mobility Test Facility *LAMA*
- Qualified test engineers

- Lander Engineering Models based on running mission and technology studies
- Incorporated sensors and DAQ