aerospacelab

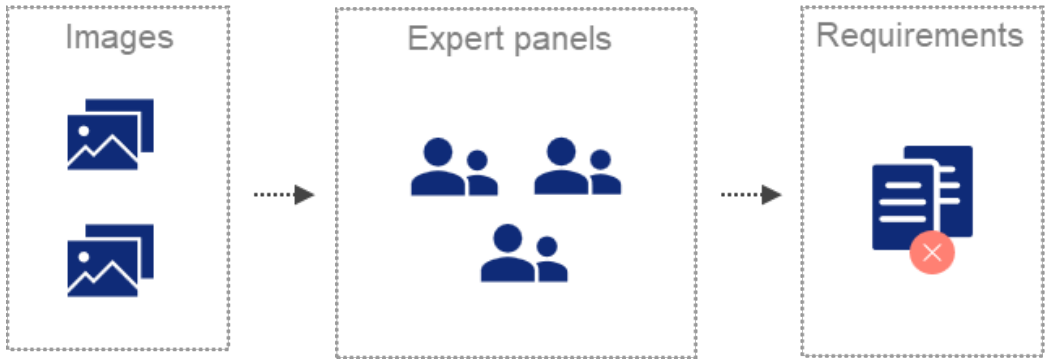
03 May 2022

Image quality
End-to-end simulations

Remote sensing payload design challenges

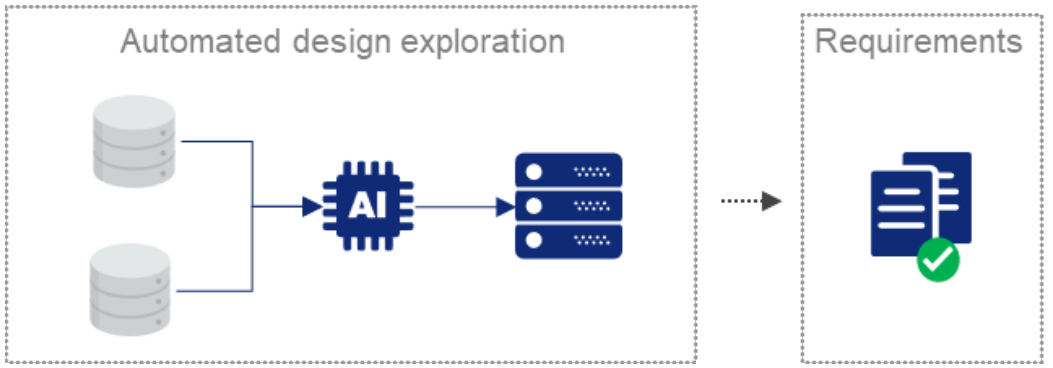
Classical design approach:

- Expert driven
- Quality matrices for quantification
- Priors and bias prone



Aerospacelab design approach:

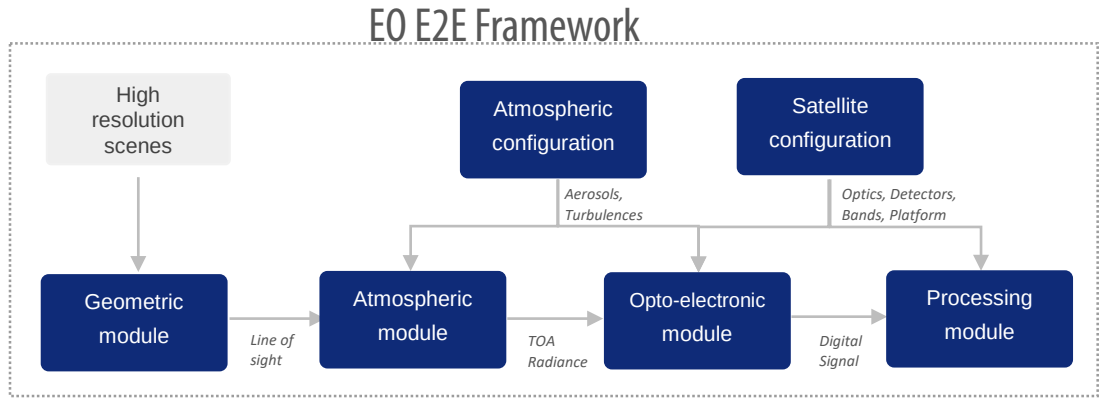
- Observations:
  - New space industry requires more and more efficient payload development, wider range of applications
  - Image processing and analytics have changed
- Analytics to the design parameters
- Joint optimization of payload and analytics

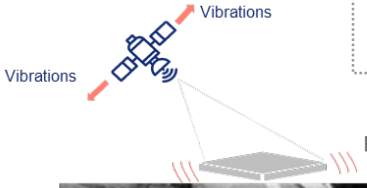


Aerospacelab design approach

End-to-end earth observing simulations

- Tens to hundreds of parameters in satellite or payload design affect image quality
- Explore various satellite designs with high fidelity and simulate physically accurate renderings.
- Coupled with image quality evaluation metrics (sharpness, noise level) to provide guideline to the design choices.





Example of spatial degradation due to the low frequency vibration (T_{vib} >> T_{int}) of the platform.

Spatial Degradation

Diffraction,
Smearing,
Resampling,
Noise,
Pixel saturation

Fig 1. High-resolution reference scene

Fig 2. Simulated satellite acquisition

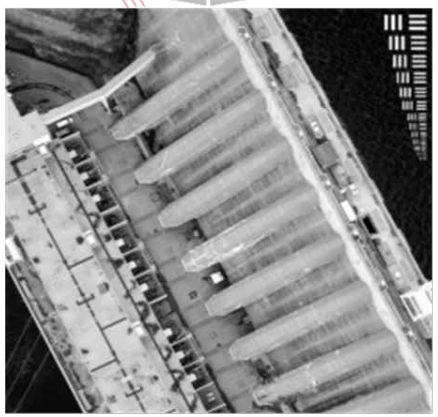


*Fig 3. Image capture with vibration amplitude of **0.1 pixel**.*

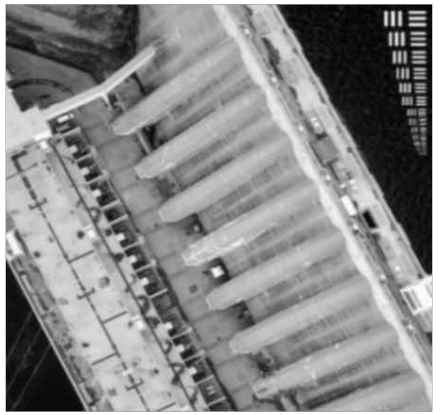


*Fig 4. Image capture with vibration amplitude of **0.5 pixel**.*

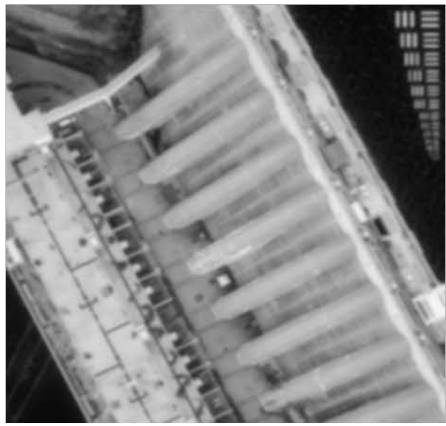


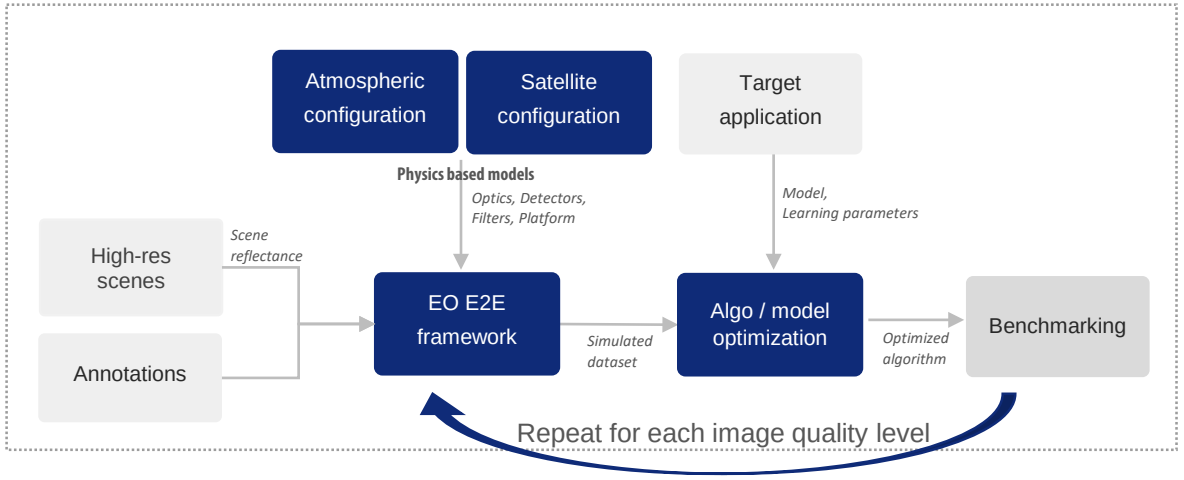
*Fig 5. Image capture with vibration amplitude of **1 pixel.***

Aerospacelab design approach

Optimization strategy

- 4 figures of merits to assess overall image quality:
  - The spectral resolution
  - The spatial resolution or ground sampling resolution (**GSD**)
  - The sharpness or modulation transfer function (**MTF**)
  - The noise level or signal-to-noise ratio (**SNR**)
- Physics-based models to link the image model (MTF, SNR, GSD) and the sensor physical properties (aperture, pixel size, etc.)
- One-to-many relation is established

Design optimization: the bigger picture



A good image is defined by its ability to extract information from it.

- CV algorithms independently optimized, for each combination of the image quality (MTF, SNR, GSD)
- Application and evaluation metrics varies (NDVI, Detection rate, NIIRS)
- In practice, only some specific key applications need to be evaluated.
- Cloud computing and a high level of parallelization with up to dozens of parallel optimization/trainings enables searching across solution space

NIIRS

NIIRS	NIIRS Criteria Task and Object	NIIRS Criteria Context
0	Not useful	Obscuration
1	Detect area	Port, Road
2	Detect building	Warehouse
3	Recognize a large Truck by type.	Roads
4	Recognize tracked vehicles, field artillery	when in groups
5	Distinguish between different vehicles such as support vans	in a known support base, when not obscured
6	Classify automobiles as sedans or station wagons	In a parking area
7	Classify individual Road markings	Railroad ties, lane markers

NDVI

Car detection

Building segmentation

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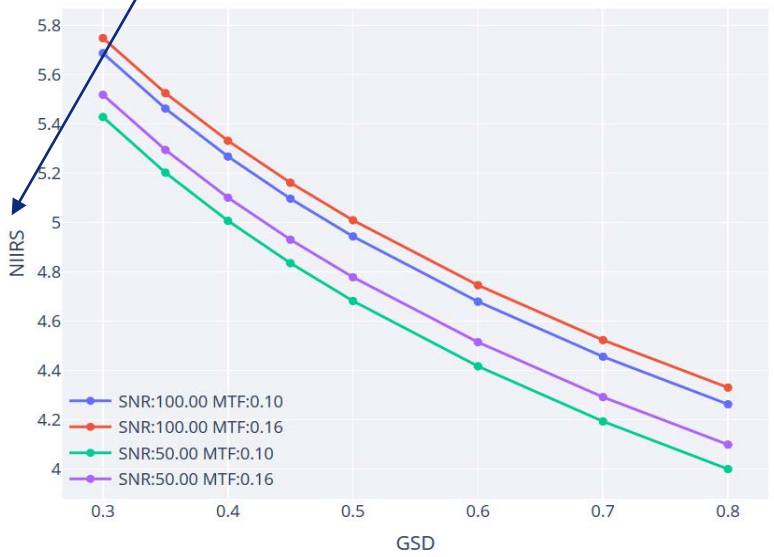
Application to high resolution (< 1m GSD) satellite design

The National Imagery Interpretability Rating Scale (NIIRS) is a well-known regression-based model relating aerial/satellite image quality, expressed in terms of fundamental image attributes.

Expert panels based



Car detection ratio. The F1 score is the harmonic mean of precision and recall for an intersection over union of 25% percent.

AI-based

Note how the curvature of both metrics are opposed and lead to different design conclusion.

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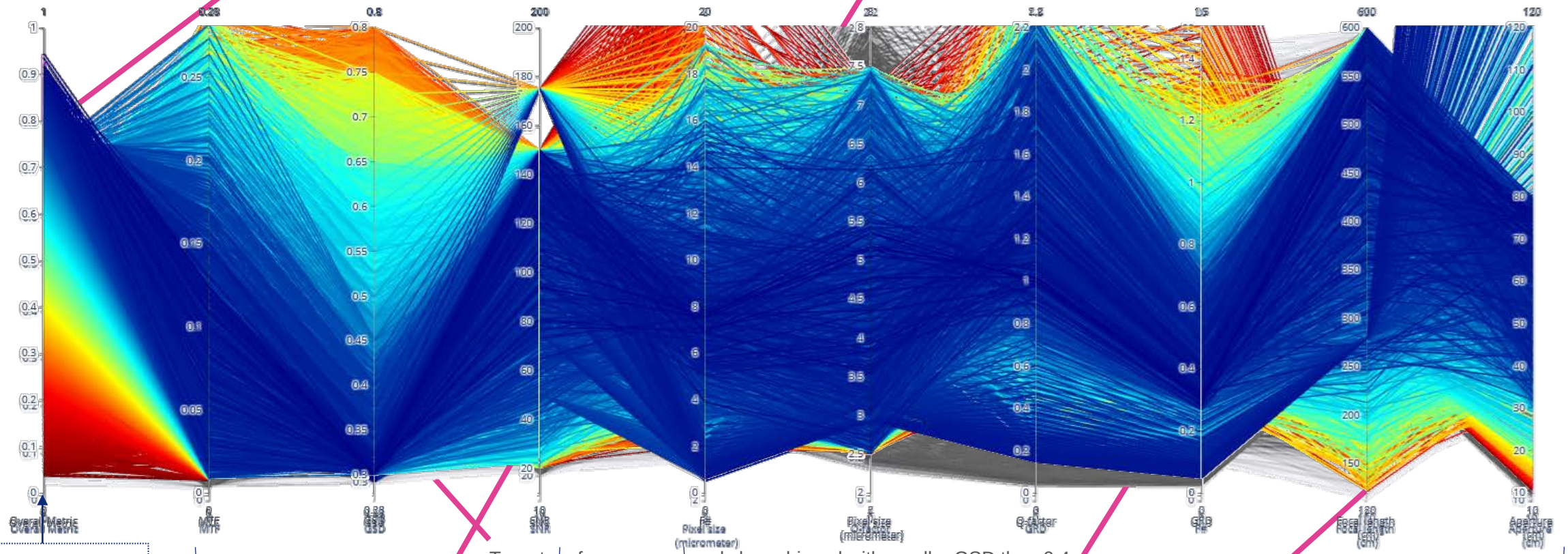
Visualization of the search space with parallel coords

Define the target performance/requirements (e.g. fighter aircraft identification performance over 80%)

Add constraint: available sensors on the market



Normalized performance on each image quality for car detection, building segmentation and NIIRS.

Target performance can only be achieved with smaller GSD than 0.4m

Image model

Derived requirement: minimal signal-noise-ratio of **~50**

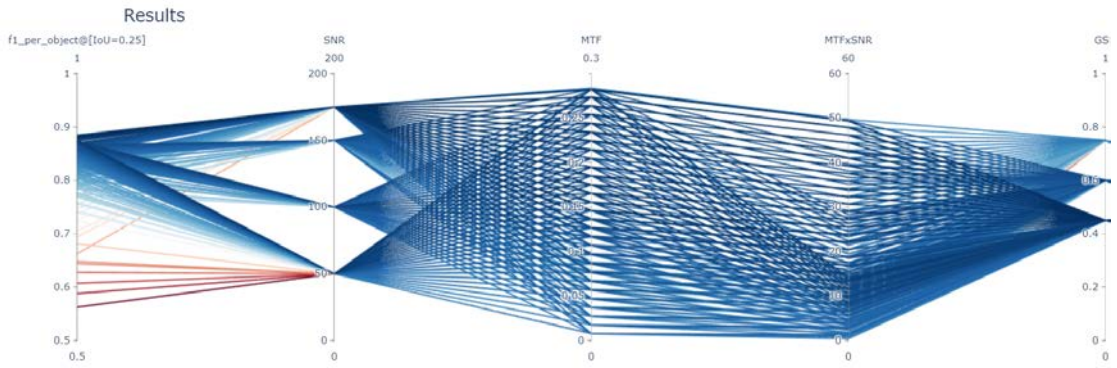
Physical properties

Derived requirement: minimal aperture of 50 cm

Key benefits of end-to-end simulation

- **Direct link between the mission requirements and design parameters**

- **Holistic view of the solution space,**
  - **Trade-off analysis made simple,**
  - **Rapid assessment of various design configurations**



- **Better defined requirements + rapid design process = Cost savings**