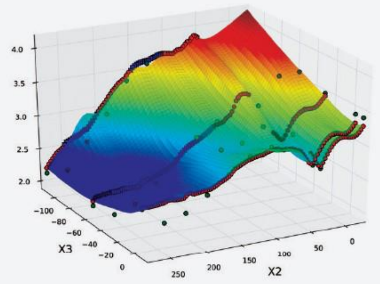
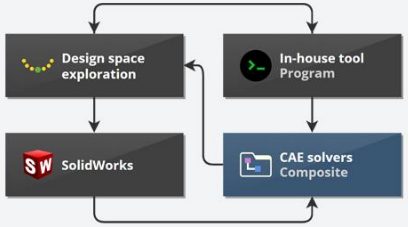
EXPLORE AND OPTIMIZE YOUR DESIGNS

pSeven





Automatic Generation of Stability Charts for Telehandler Vehicles

A presentation by DATADVANCE
in collaboration with MANITOU

October 2022

MANITOU

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Manitou: Presentation of the Company

A LOCAL REGIONAL COMPANY
became an international group

1945
Andrée Braud is developing a construction company in Ancenis.

1958
Birth of the Manitou forklift -truck based on the idea of Marcel Braud.

1972
Opening of the 1st subsidiary in the United Kingdom.

1981
Launch of the 1st Manitou telehandler.

2008
Acquisition of the American company Gehl Company.

Company created in 1859, purchased in 1902 by **John Gehl.**

2018
More than 800,000 machines sold worldwide.

Manitou: Product Overview

INNOVATIVE PRODUCTS designed to last

TELEHANDLER

ROTATING TELEHANDLER

HEAVY-LOAD TELEHANDLER

ROUGH-TERRAIN FORKLIFT TRUCK

ARTICULATED LOADER

AERIAL WORK PLATFORM

TRUCK-MOUNTED FORKLIFT

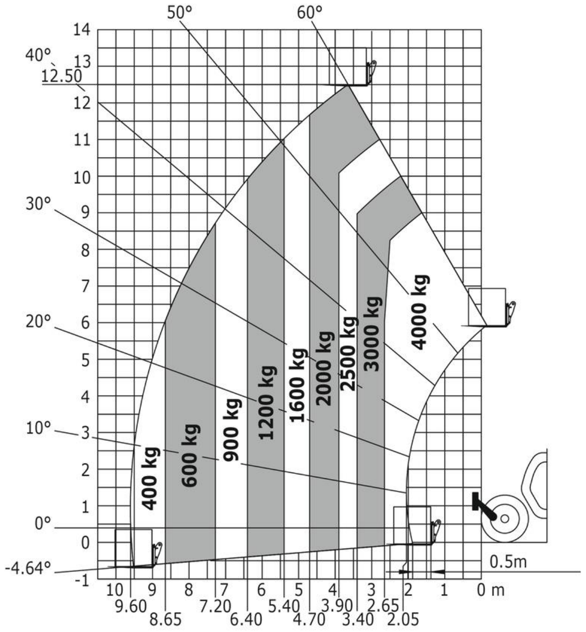
INDUSTRIAL FORKLIFT TRUCK

WAREHOUSING EQUIPMENT

- Construction market
- Agriculture market
- Industrial markets

Introduction to the Static Stability Problem

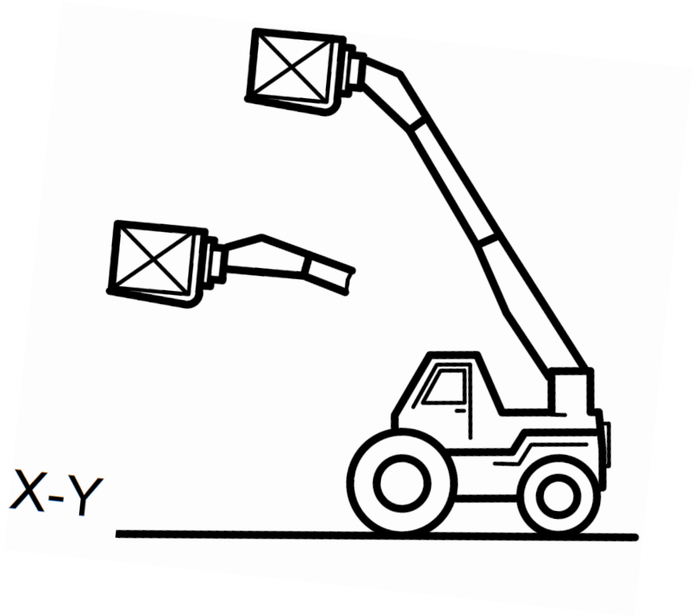
- Manitou needs to provide customers with stability diagrams for the different attachments (forks, buckets, clamps…) that can be attached to each telehandler vehicle
- A stability diagram indicates the maximum extension and elevation that can be reached for a given weight before the vehicle starts tilting
- For the attachment provided by default, the diagram can be obtained experimentally, but an automated method is needed for the large variety of possible attachments



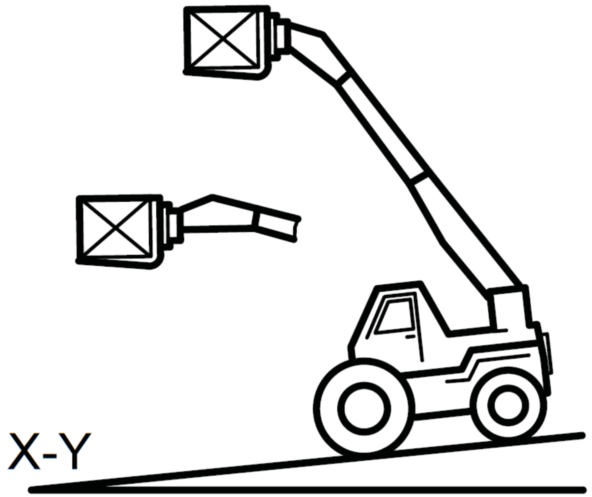
Static Stability Requirements (Regulations)

- The static stability diagram is the result of the most restrictive combination of three situations for every load and arm position (extension and elevation angle) and attachment type:

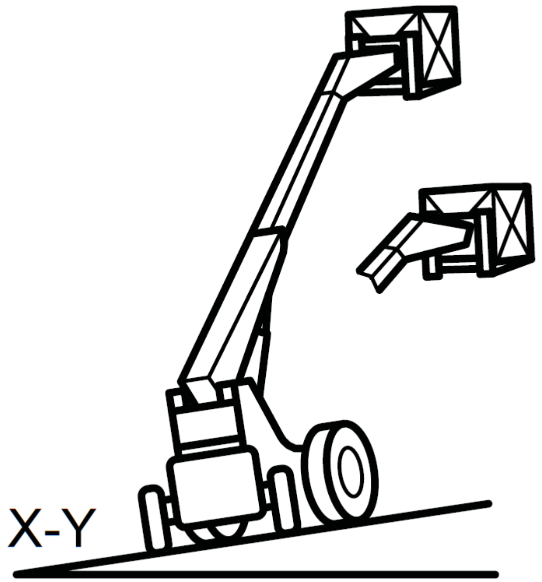
Flat ground:



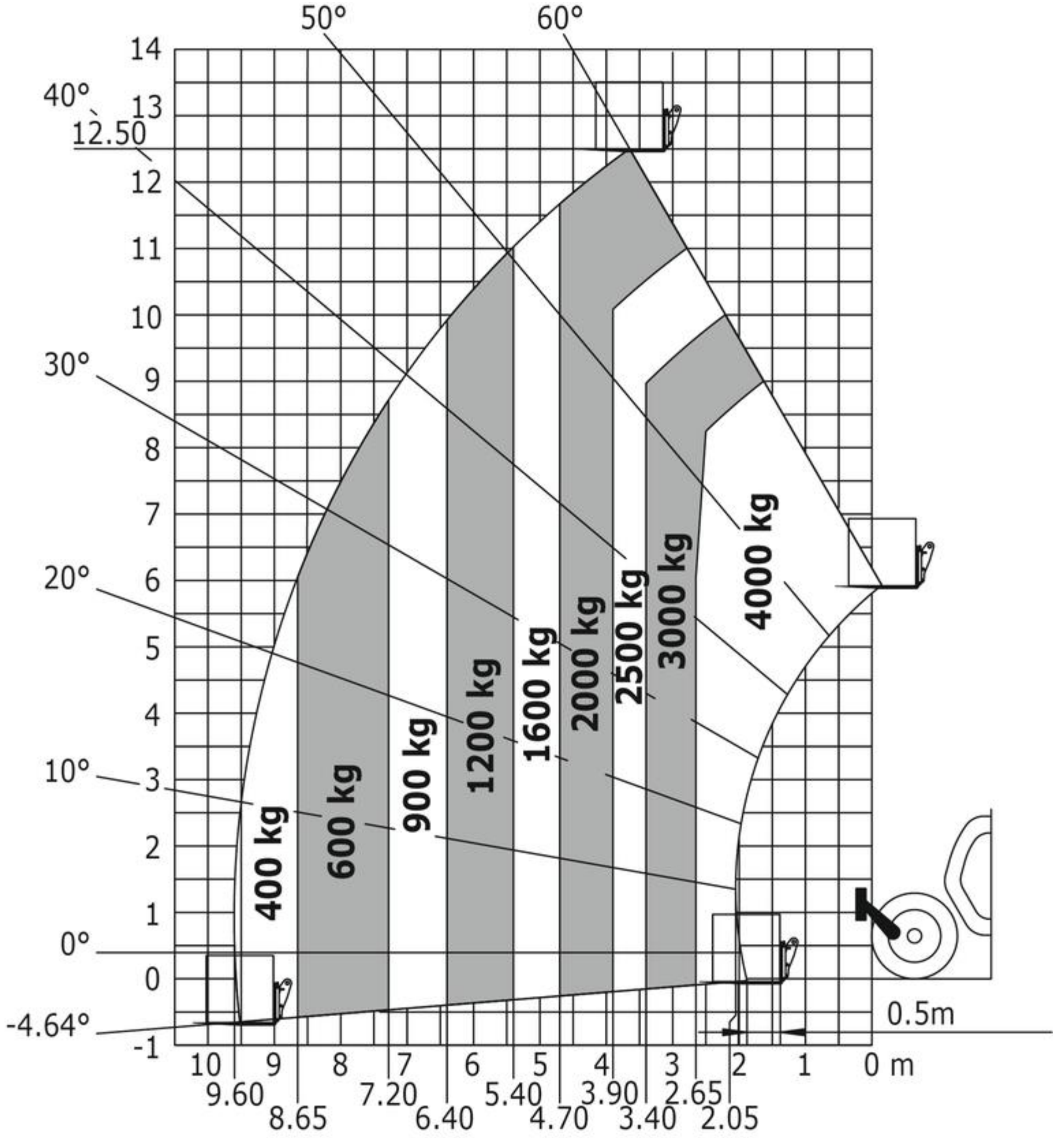
Downhill:



Lateral slope:



Static Stability Diagram Interpretation



For a given load (mass) and attachment type, the diagram indicates how far and high it can be safely carried (ensuring the static stability)

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Classical Method and its limitations

The current method for stability chart generation consists in performing experimental tests during which (for each load level and ground inclination) several combination of arm length/height are reached until the wheels start losing contact with the ground, which indicates the limit of the stability region.

Advantages:

- Closest to real-life operation conditions (so results should be exact)

Disadvantages:

- Costly: Experimental setup and telehandler operator
- Time consuming: Many different required combinations of loads and telescopic arm positions, as well as great variety of possible attachments

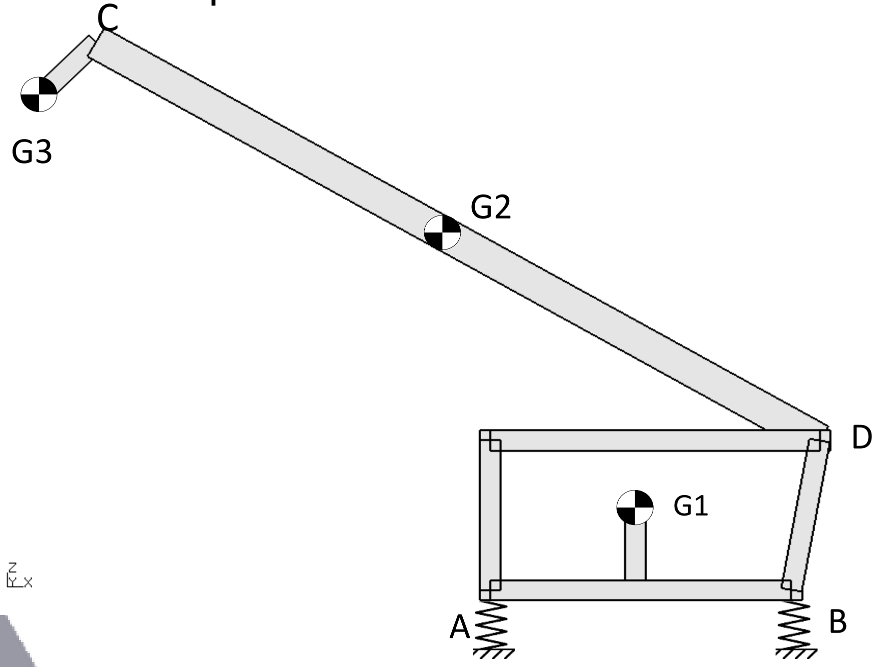
Previous to the current study, theoretical computations considering a rigid body model were developed by Manitou, but they not allow to consider effects such as the flexibility of the tires and the telescopic arm.

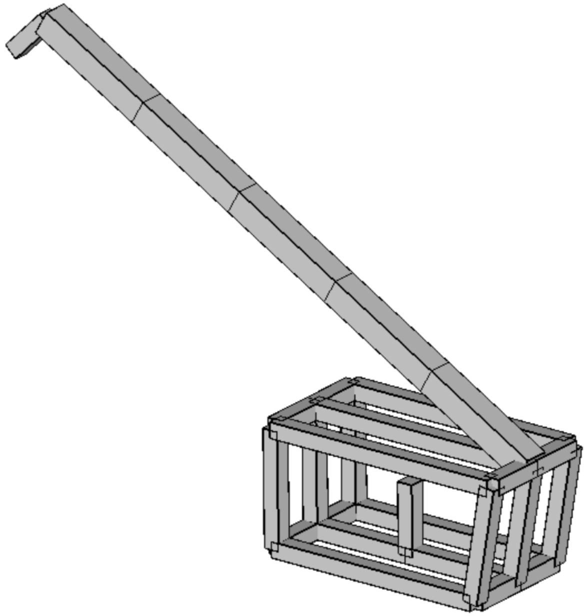
Proposed Approach

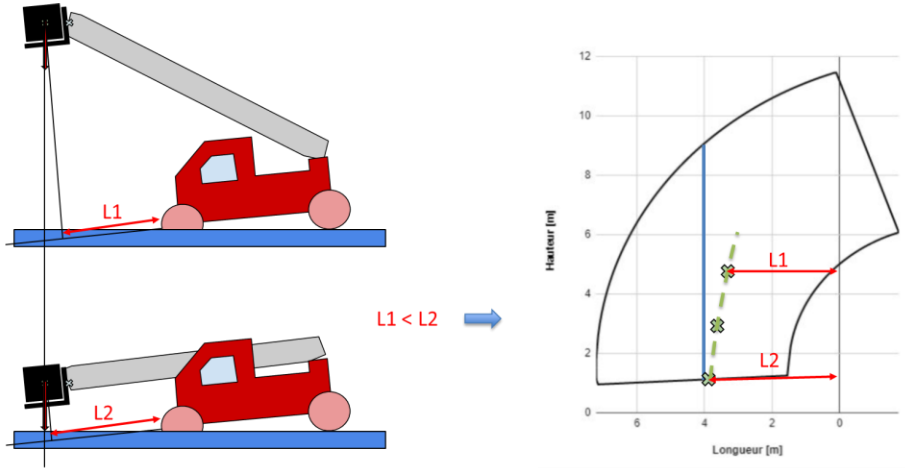
- Create a FEM parametrized with the dimensions of the vehicle, the position of the telescopic arm and the mass distribution of the vehicle and load
- Extract reaction forces (normal to the ground) applied to the wheels. Static stability limit is defined when two wheels lose contact with the ground (zero reaction force).
- Negative (normal) reaction forces are not feasible, but the bring information about how far an operating point is from the stability limit
- Steps for building a diagram
  - For each scenario (flat, downhill, lateral), create a DoE with variables describing the position of the arm, position of the load relative to the arm, and load. The force of the critical wheel (depending on the scenario) is collected as output
  - Build an approximation model of the force on the critical wheel as a function of described inputs
  - Use Adaptive Design of Experiment (ADoE) to find a collection of critical points (FN = 0) for each scenario
  - Create the feasible region according to each criterion
  - Obtain the diagram as the most restrictive combination (intersection) of all the previous regions
- Advantages:
  - Automated approach
  - Attachments are characterized using their geometrical and mass properties
  - Reduced cost, complexity, and time compared to experimental testing
  - More accurate results compared to classical rigid-body methods (geometrical nonlinearities due to flexibility considered)

Methodology: Nonlinear Finite Element Model

- FEM: Used to represent the flexibility of the tires (idealized as springs) and the telescopic arm (beam elements), as well as the mass distribution of the vehicle and load
- FEM inputs (node coordinates, element properties) are functions of DoE variables (arm position, relative position of the load, mass)
- Nonlinear Analysis: The structural displacements affect the loads applied to the structure; a nonlinear geometrical analysis is required for more accurate prediction of the critical load. Example: Tire flexibility makes the downhill scenario more unstable compared to the rigid body assumption







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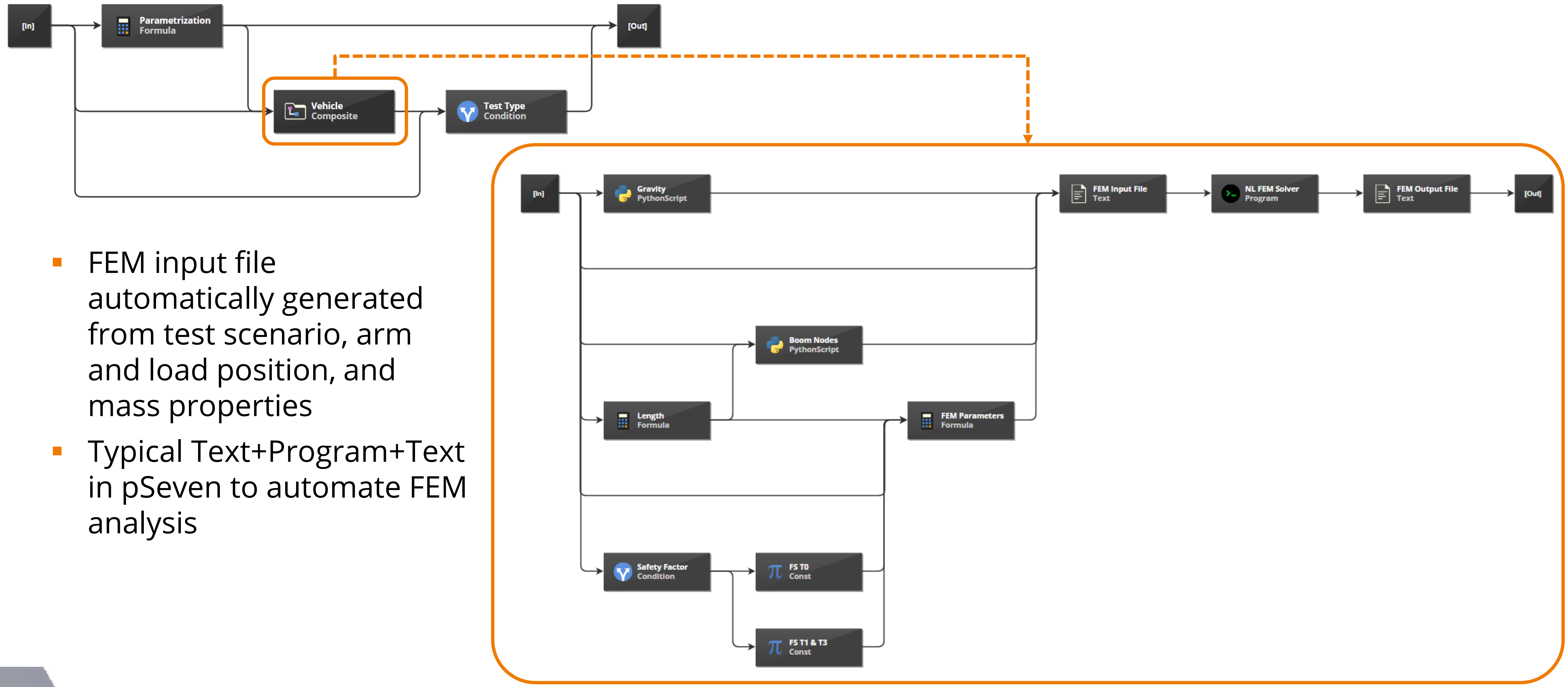
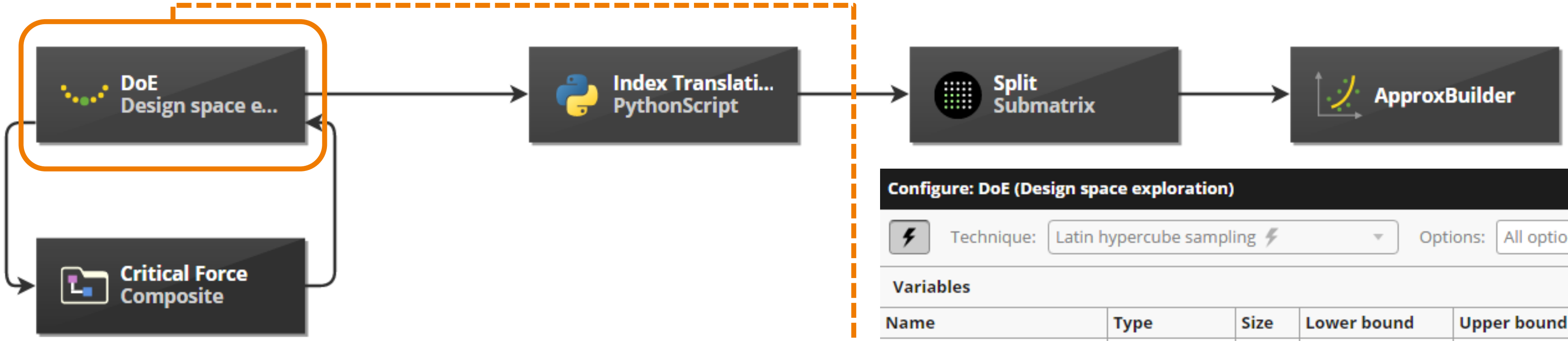
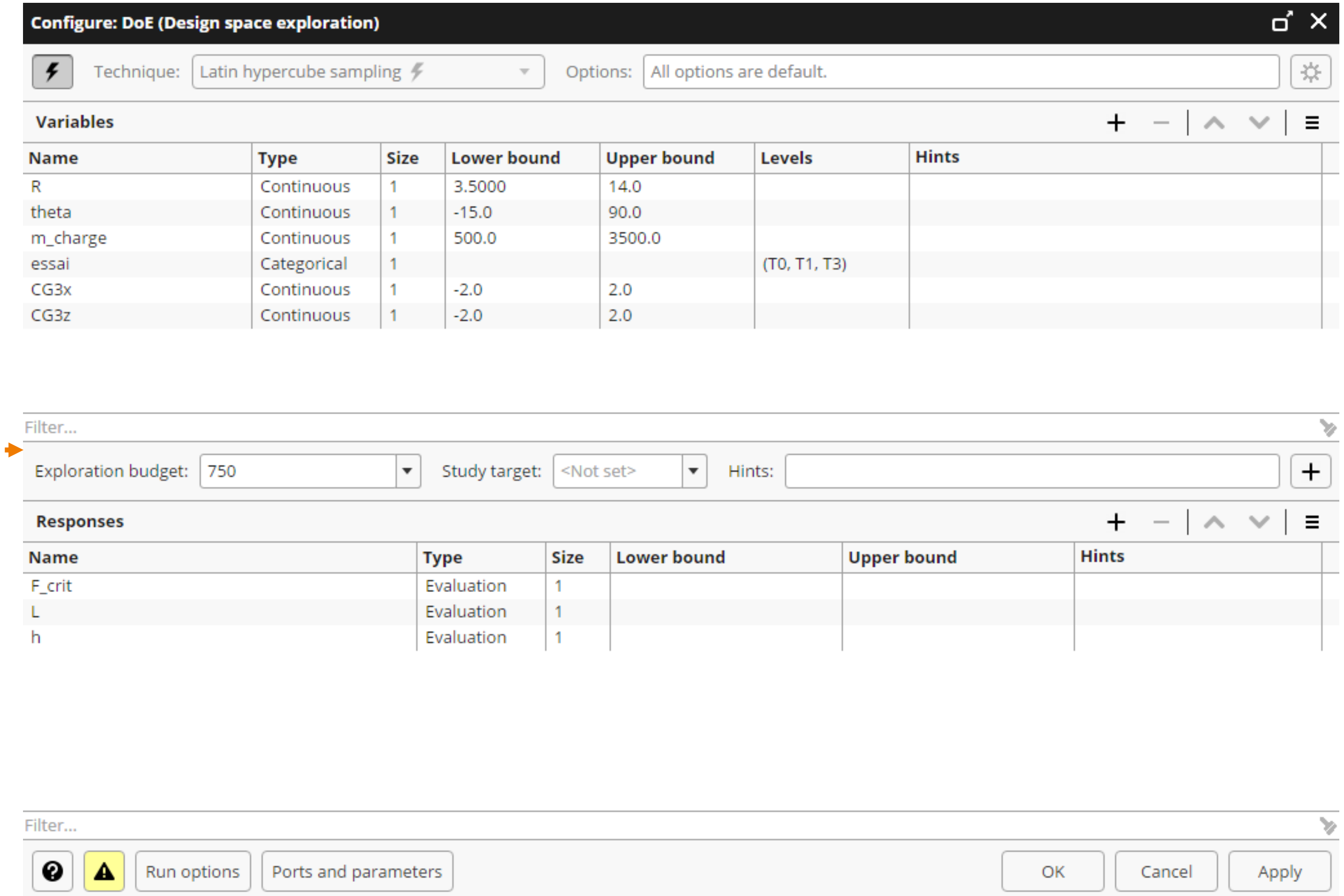
Methodology: FEM setup and results postprocessing according to load condition



- FEM input file automatically generated from test scenario, arm and load position, and mass properties
- Typical Text+Program+Text in pSeven to automate FEM analysis

Methodology: Design of Experiment and Surrogate Model Training





- DoE is performed with variables describing arm extension and angle, load position relative to the arm tip, and load mass
- The reaction force value on the critical wheel (which depends on the test scenario) is collected as an output
- Cartesian length, height, collected as outputs for further plotting
- Approximation Model Trained from DoE

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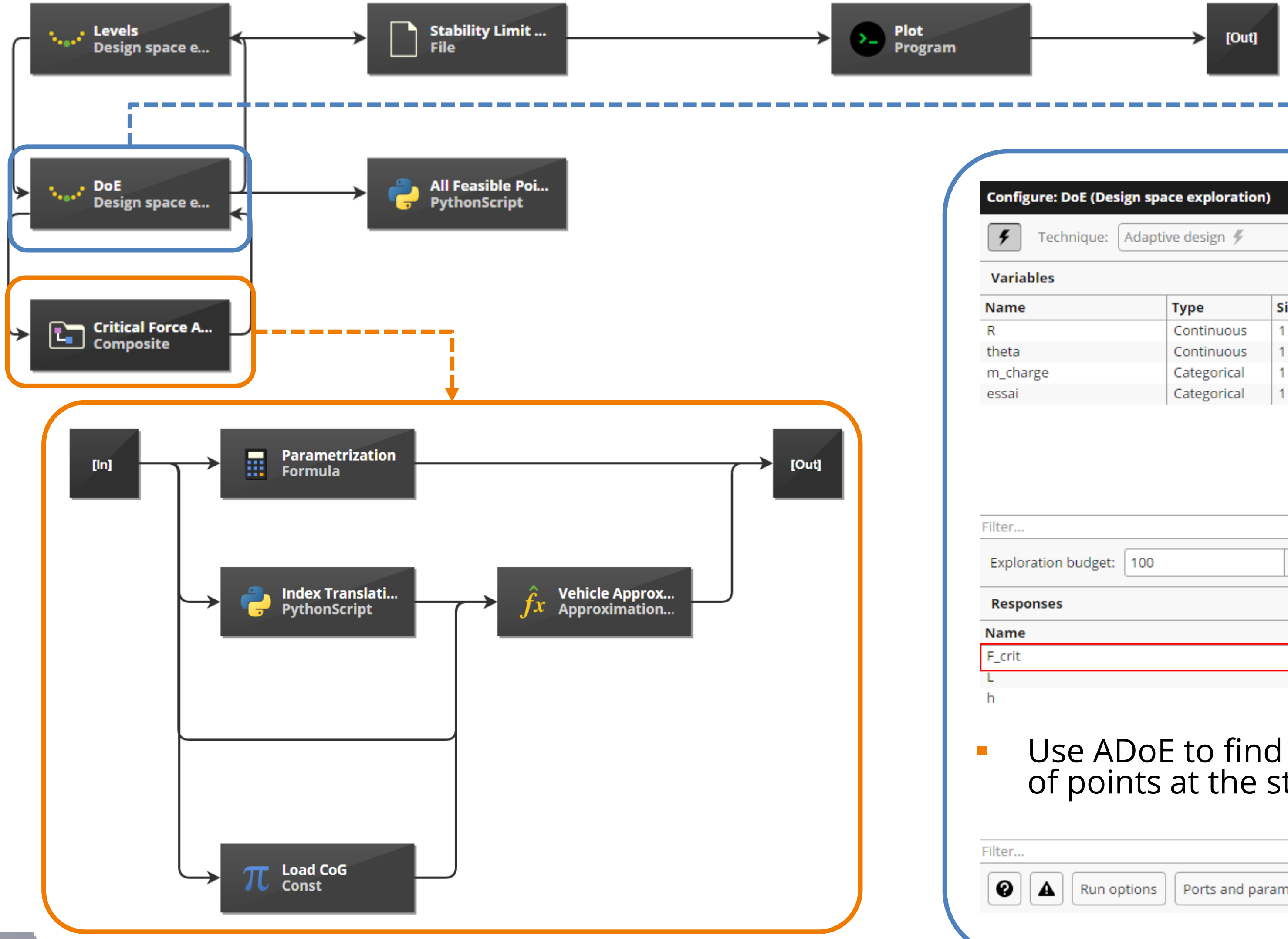
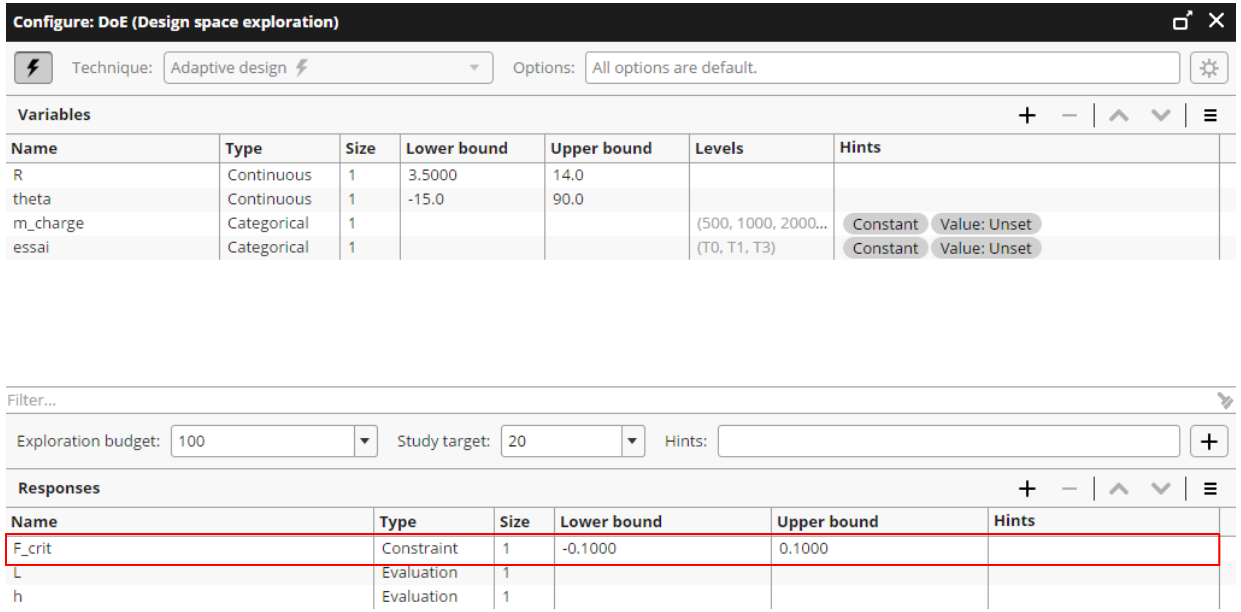
Automated Search of Static Equilibrium Boundaries





- Use ADoE to find (for each load mass level and scenario) collections of points at the stability limit (Force on critical wheel ~0)

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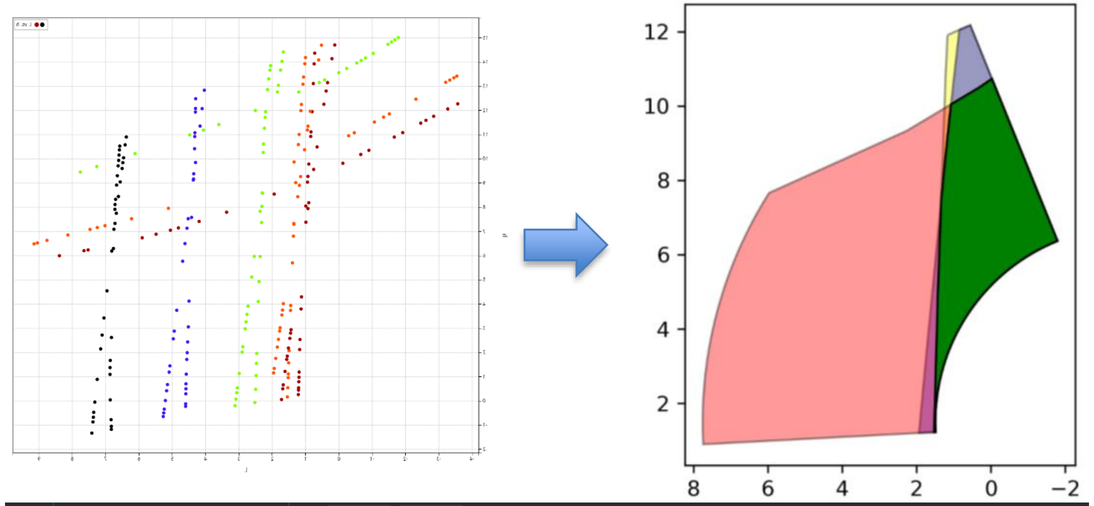
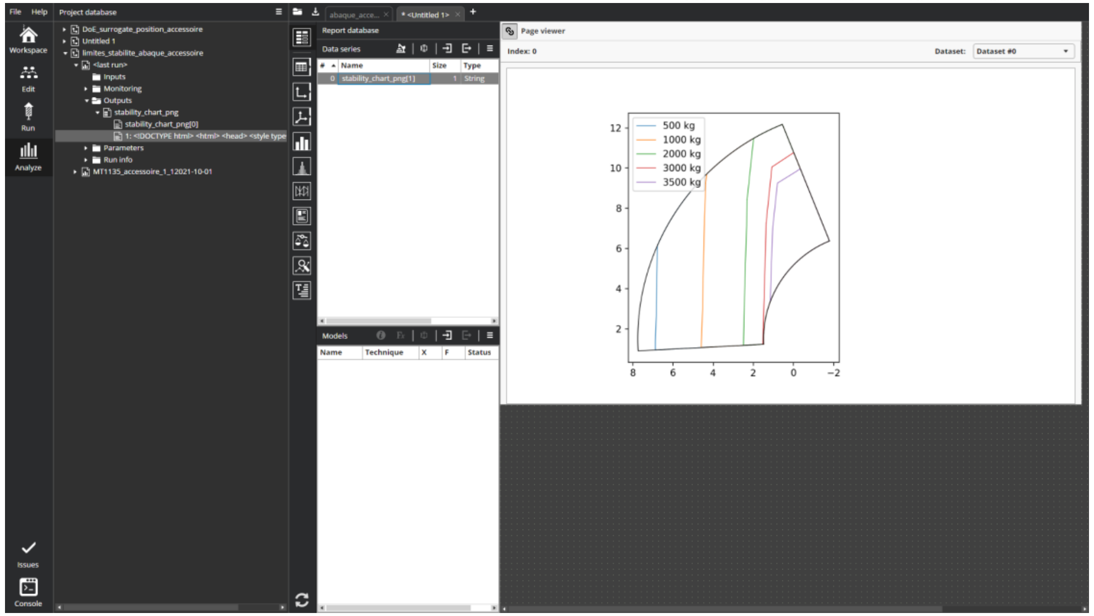
Methodology: Automated Creation of Diagrams

- For each load mass level, and for each scenario, determine the stability region regarding each particular scenario
- For each mass level, the stable region (regarding all criteria simultaneously) is obtained as the area shared by all the regions (intersection of all criteria)
- Diagram creation is automated in a Python script
- It is part of the previous workflow, either as a PythonScript block or encapsulated in a .exe (using Program block) for better portability
- Generated diagrams can be monitored as ports in pSeven and displayed in a report





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Conclusions and Perspectives

- Automated approach
- Includes flexibility of tires and telescopic arm, thus a more realistic model
- Attachments are characterized using their geometrical and mass properties, allowing to quickly generate diagrams for a large variety of attachments
- Reduced cost, complexity, and time compared to experimental testing
- More accurate results compared to classical rigid-body methods (geometrical nonlinearities due to flexibility considered)
- The workflow for stability boundary search is independent on the source of data
- Thus, it can be used with approximation models trained with data of various sources:
  - Experimental
  - More accurate or geometrically representative FEM models
- Multiple sources can be combined into a single model using DataFusion
- Diagram creation is part of the workflow and results can be monitored and stored in the database, as well as used in a report with Page viewer

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