NSGA-HYBRID Performance Evaluation

A comparison of modeFrontier's NSGA-II and HYBRID MDO algorithms for a single-objective design problem, using autonomous optimisation parameters

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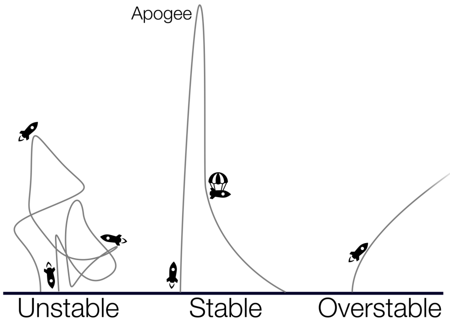
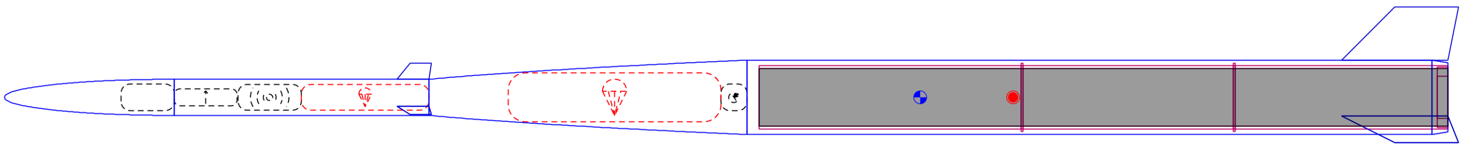
Introduction

The NSGA-II and HYBRID algorithms in modeFrontier have been identified as two potential tools for optimising high-powered rockets. To maximise the apogee (altitude) of record-breaking rockets, many design variables must be adjusted to reach a solution which is stable (see below) and capable of (literally) reaching new heights.

The apogee maximisation problem is single-objective, so algorithms tailored for multi-objective optimisation were not deemed appropriate. Exploring the range of algorithms available in modeFrontier for single-objective problems, the NSGA-II and HYBRID algorithms were identified as those with the most potential. They are appropriate for problems involving discontinuities (a discontinuity in apogee occurs where stability passes through 0), and are relatively computationally efficient. Since openRocket simulations can run relatively quickly, 'virtual' design evaluation (using RSMs) is not favourable.



Evaluation of the relative performance of each algorithm was conducted using a complex rocket design. The 'APEX-K Kinetic Dart' was used, as illustrated below. The design was to be optimised for a maximum 'dart' apogee (the top section separates after motor burnout to reduce drag). Input variables included the length of each body tube and nosecone, and the heights of both sets of fins.



NSGA-II

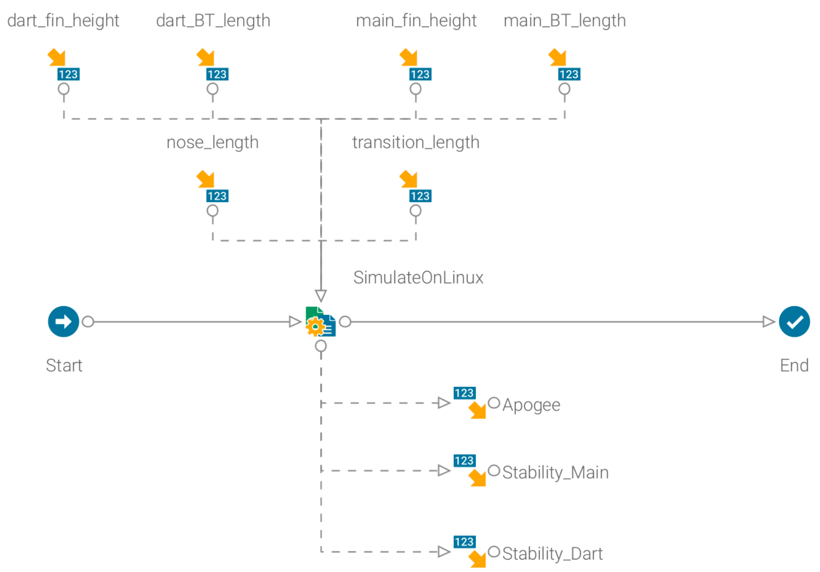
Full details on the NSGA-II algorithm can be found in modeFrontier documentation; a "smart non-dominated sorting strategy" is employed to reduce the number of computations required. For this test, the 'autonomous' mode was used for simplicity; this implements automatic stopping criteria which attempt to identify when an optima has been reached.

HYBRID

The modeFrontier HYBRID algorithm is appropriate for single and multi-objective problems. again, full details can be found in documentation. This combines a genetic algorithm with an SQP optimiser; sorting is achieved using the same methods as NSGA-II. An additional GA operator is used to 'insert' the SQP algorithm, which runs in parallel with the GA, although SQP does not perform concurrent evaluations within itself. HYBRID uses modeFrontier's AFilterSQP algorithm, "adapted for multi-objective problems with different techniques". The goal of this investigation is to evaluate whether the addition of SQP optimisation improves the results obtained by the genetic algorithm. Again, HYBRID was operated in 'autonomous' mode; this ensured simplicity and consistency with the NSGA-II implementation. It's stopping criteria are defined in a very similar manner to the NSGA-II autonomous mode.

Workflow

The same workflow was used for each algorithm; 6 input parameters were set as variables for optimisation, and 3 output parameters were measured. Constraints were used to enforce stability at launch (using Stability_Main) and at separation of the dart and the lower stage (Stability_Dart). A single objective was defined to maximise apogee. OpenRocket simulations were executed on a remote Linux server using the



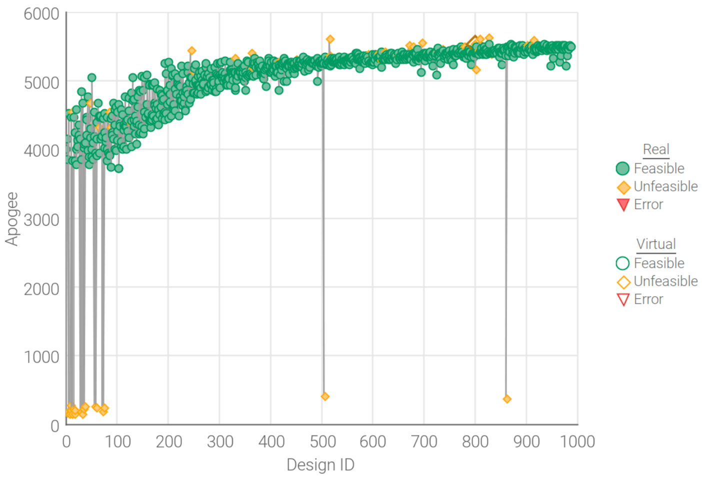
Results

The NSGA-II algorithm conducted more evaluations for this workflow, reaching a significantly better optimum solution. Filtering the NSGA-II results to the first 628 designs, the maximum apogee (satisfying constraints) was 5421m, which is less than the value HYBRID reached for the same number of evaluations. This suggests that the HYBRID algorithm approaches optima faster than NSGA-II, but it's automatic stopping criteria perform worse for this case.

It may be possible to adjust the HYBRID stopping criteria or use self-initialisation to run the algorithm for a greater number of evaluations. It is evident that, although faster, HYBRID requires a similar number of evaluations to find an optima when compared to NSGA-II. Running the HYBRID algorithm up to 953 evaluations would be an interesting 'next-step' in this investigation, helping to understand the extent to which this holds true.

	NSGA-II	HYBRID
Design Evaluations	953	628
Feasible	872 / 92%	560 / 89%
Unfeasible	81 / 8%	68 / 11%
Max' Apogee (satisfying constraints)	5539 m	5461 m
Minimum distance to constraints	4%	16%

NSGA-II



HYBRID