PEDALS

Parametric Entry Descent and Landing Synthesis

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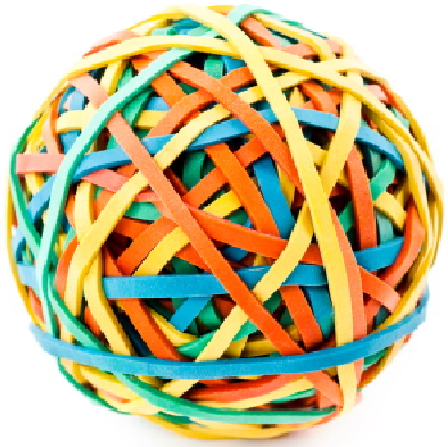
OVERVIEW

- Who, What
- Objectives, Scope
- Method
- Representation
- System Design, Assumptions
- Implementation
- Next Steps

WHO / WHAT

- Aevo: startup mode, R&D focus, founded in 2010
- ESA incubator @ Munich
- Technology transfer of optimisation methods and software

Methods	*Implementations*
TABU SEARCH	DISTRIBUTED
GAME THEORY	PARALLEL
SIMULATED ANNEALING	HANDHELD
METAHEURISTICS	INTEGRATED
STOCHASTIC SEARCH	REUSABLE
GRADIENT METHODS	FRIENDLY
MONTE CARLO SIMULATION	EXTENSIBLE
EVOLUTIONARY COMPUTING	VISUAL



OPTIMISATION ENGINES

DESIGN

Tools that explore the system design space to find the most robust options.

DEVELOP

Tools that find the best trade-off between conflicting objectives without violating the constraints.

OPTIMISATION ENGINES

SCHEDULE

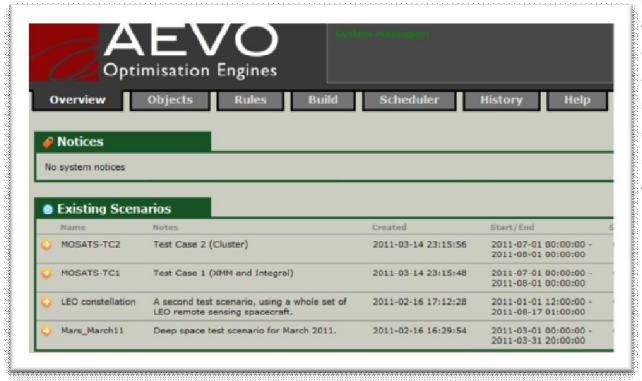
Tools that optimise task or team schedules to improve resource usage.

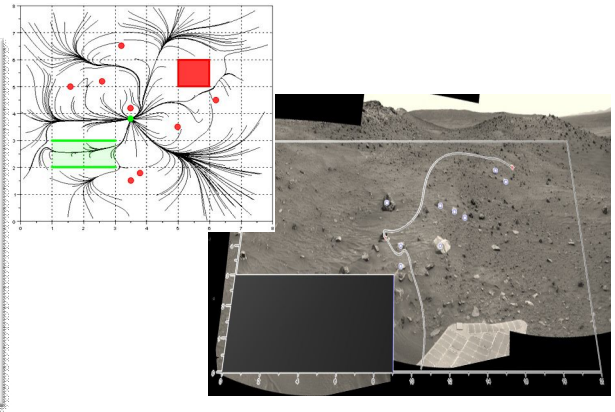
OPTIMISE

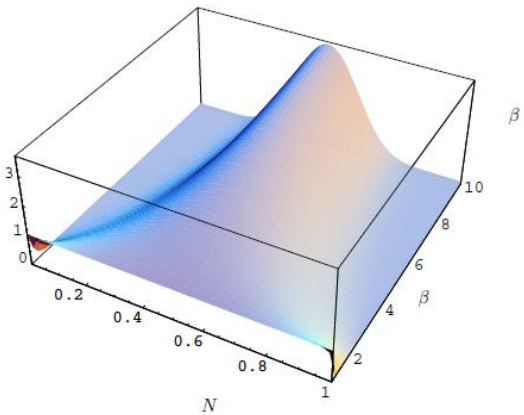
Tools that fine-tune a system calibration to increase efficiency and representation quality.

APPLICATION AREAS

SCHEDULING	ROUTING / TRAJECTORY DESIGN	DESIGN
Spacecraft onboard task executives	Rover path planning	Explore tradespaces
Ground segment operations (multi-s/c, multi-station)	UAV/satellite formation flying	Parameter tuning
Resource/Team allocation	Dynamic chase/escape/intercept flight	Pareto optimisation
Logistics / Transportation	Rendezvous/berthing control	Decision support







PEDALS OBJECTIVES

- Demonstrate use of general purpose engine as decision support tool, especially during trade-off analysis
- EDL is great case to study since there are several strongly competing design goals and (at least in Europe) few available tools
- Evaluate performance and usefulness of approach; compare with previous and ongoing developments
- Maintain highly modular approach, interfacing (but not integrating) with relevant models
- Re-use existing codes (platform independence)
- Proof-of-concept only (efficiency and ‘elegance’ secondary to functionality)

APPROACH

- Use and develop simplest possible tool set
- Avoiding any closed, commercial or protected code
- Focus on user interaction and results without assuming detailed understanding
- Hybrid genetic algorithm for ‘design’ of EDL architectures: implicit trade-offs through exploration vs. exploitation of design space
- Understand the validity of using stochastic methods for design, and to develop a highly modular demonstrator for our in-house technology developments
- It is not intended to provide a high fidelity flight simulation, nor any solutions to a given exploration challenge

EVOLUTIONARY COMPUTING

- Bio-inspired population-based algorithms, mimicking natural selection
- Solutions encoded as parameters (genes) and concatenated into structured strings (chromosomes)
- Initially random population of solutions evolves in response to different operators (reproduction selection, crossover, mutation)
- EDL design is a multi-objective problem: optimise conflicting objectives subject to constraints
- Avoid aggregate functions:

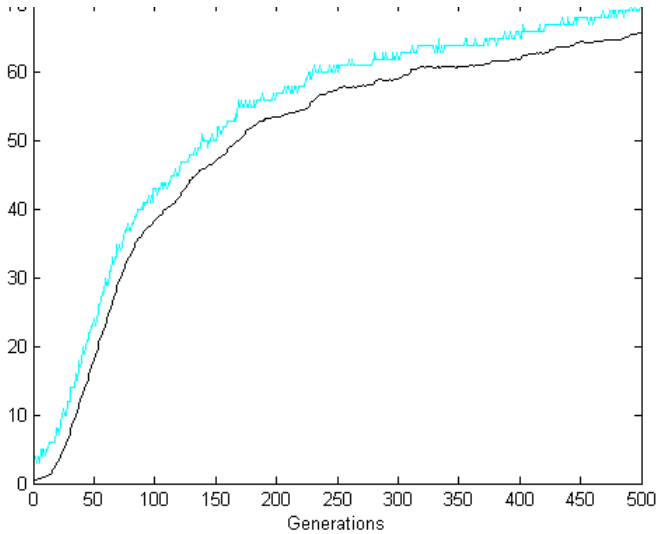
  elephants + parachutes $\neq$ apples + aeroshells

GENGA/PR ALGORITHM

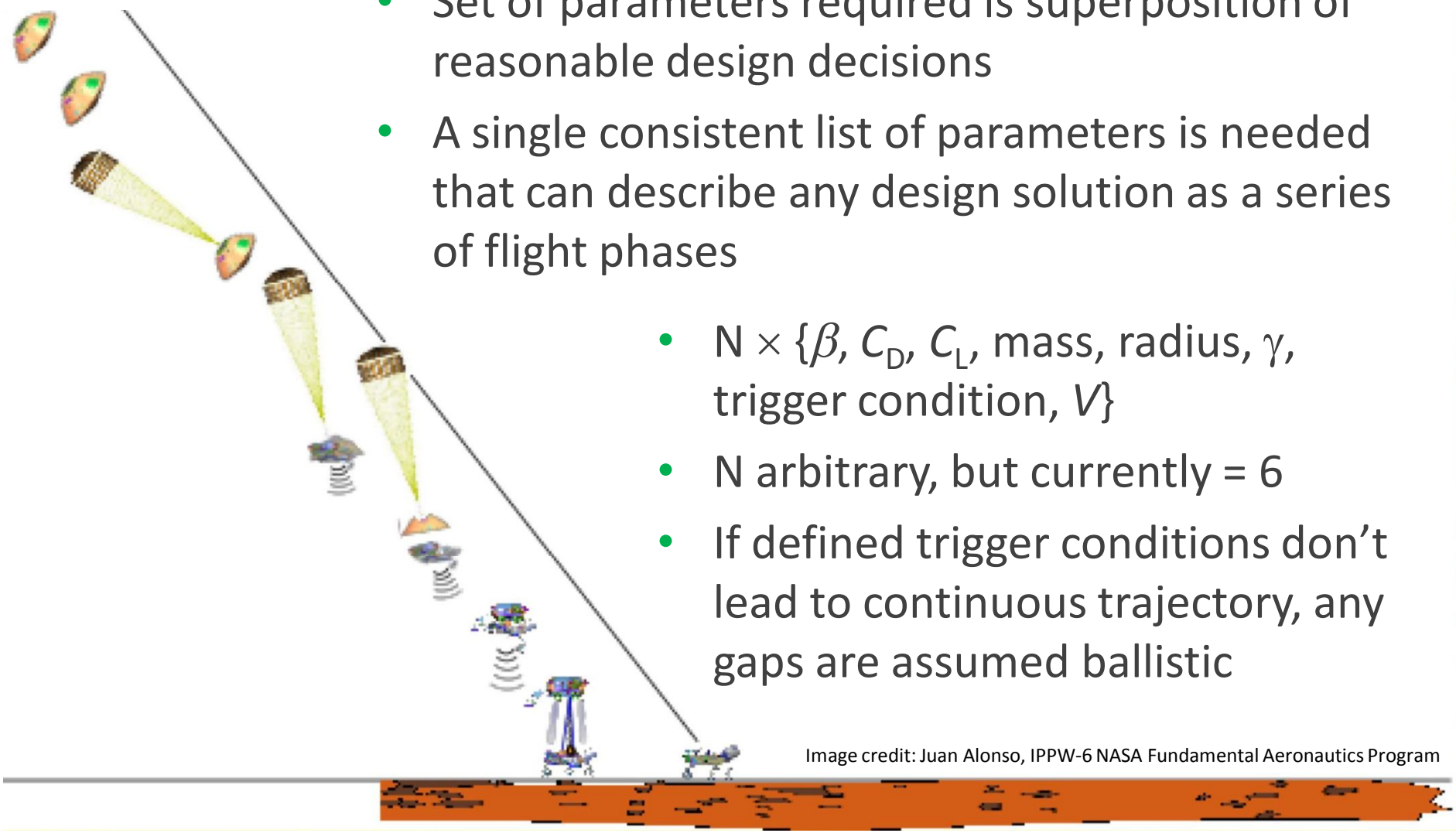
- Value of a candidate design described as distance from Pareto optimal front
- Elite set chosen as diverse members of optimal front
- Improvements in solutions at population level manifest as increasing volume of designspace behind the front (!)

$$\exists a \in A : \vec{a} \succ \vec{x}; \circ \leftarrow \text{iff}$$
$$\exists i \in \{1..k\}, f_i(\vec{a}) > f_i(\vec{x})$$
$$\wedge \forall i, f_i(\vec{a}) \geq f_i(\vec{x})$$

Chromosome 1	1101100100110110
Chromosome 2	1101111000011110
Offspring 1	1101111000011110
Offspring 2	1101100100110110
Offspring 1*	1100111000011110
Offspring 2*	1101101100110100



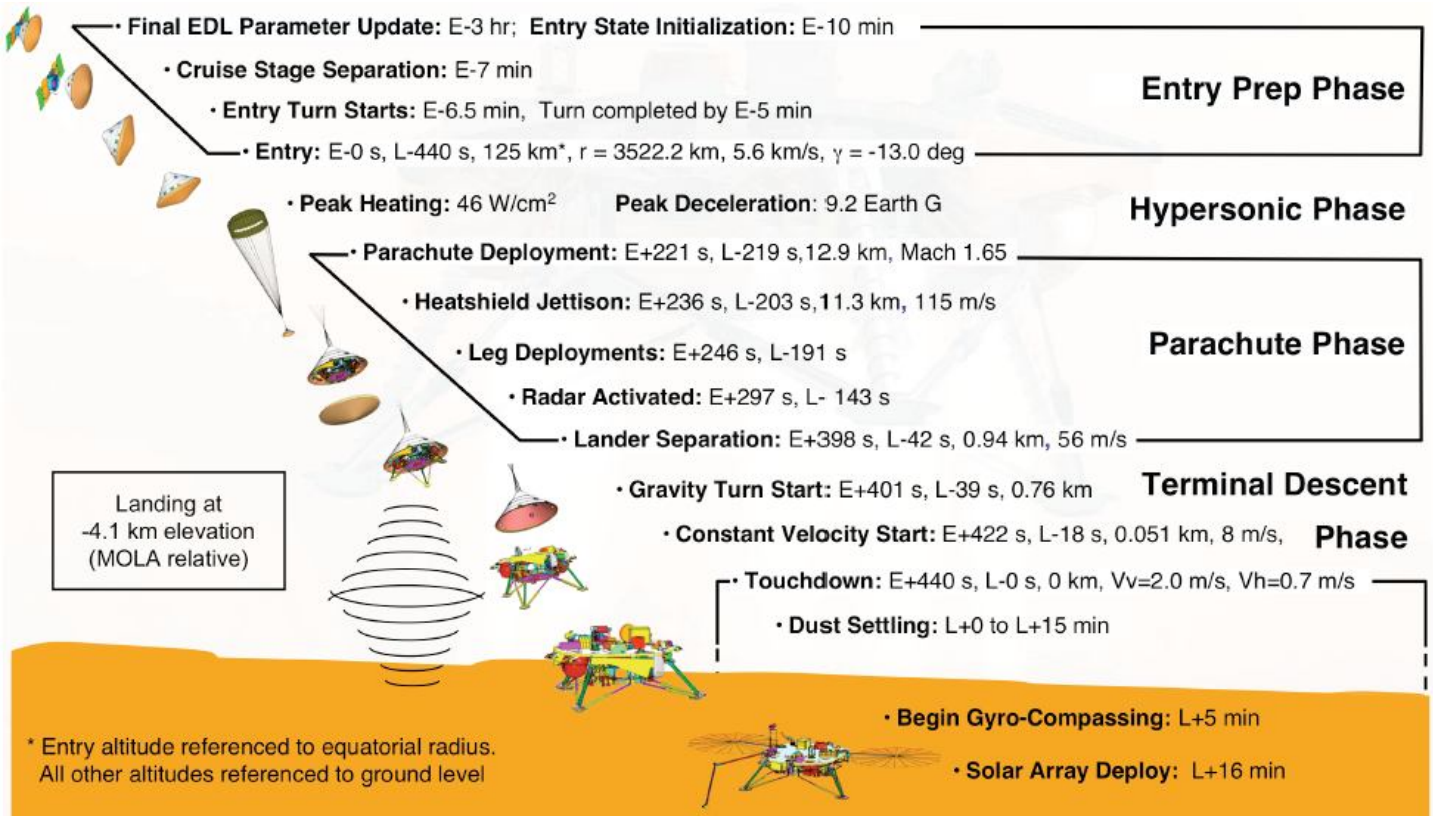
REPRESENTATION



- Set of parameters required is superposition of reasonable design decisions
- A single consistent list of parameters is needed that can describe any design solution as a series of flight phases
  - N × {β, C_D, C_L, mass, radius, γ, trigger condition, V}
  - N arbitrary, but currently = 6
  - If defined trigger conditions don't lead to continuous trajectory, any gaps are assumed ballistic

Image credit: Juan Alonso, IPPW-6 NASA Fundamental Aeronautics Program

EXAMPLE



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320A140750000000F00100227200BC000000000000
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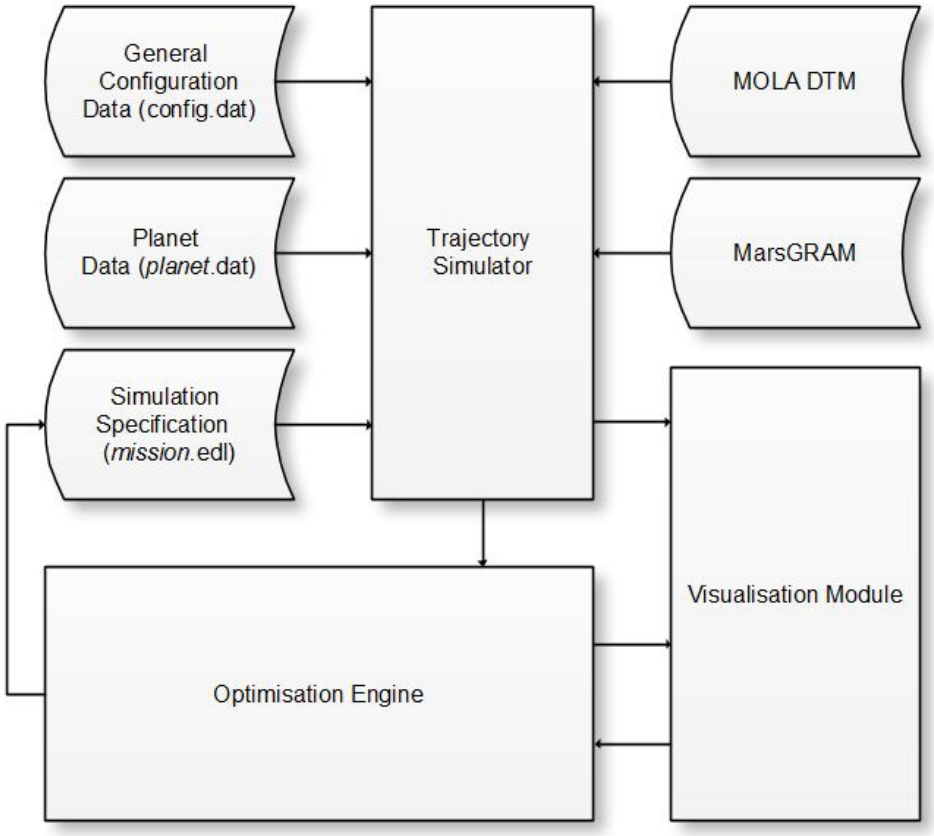
Image: Aerodynamics for the Mars Phoenix Entry Capsule, K.T. Edquist, P.N. Desai, M. Schoenenberger, AIAA

ASSUMPTIONS

- No cross-track control; no active bank control
- Constant gravity
- Non-rotating atmosphere
- C_D, C_L speed invariant within discrete flight phase
- Mass changes only at flight phase transitions
- Designs are quantised onto representable values

SYSTEM DESIGN



- Modular code blocks
- Easy to adapt / integrate;
- Not easy to validate

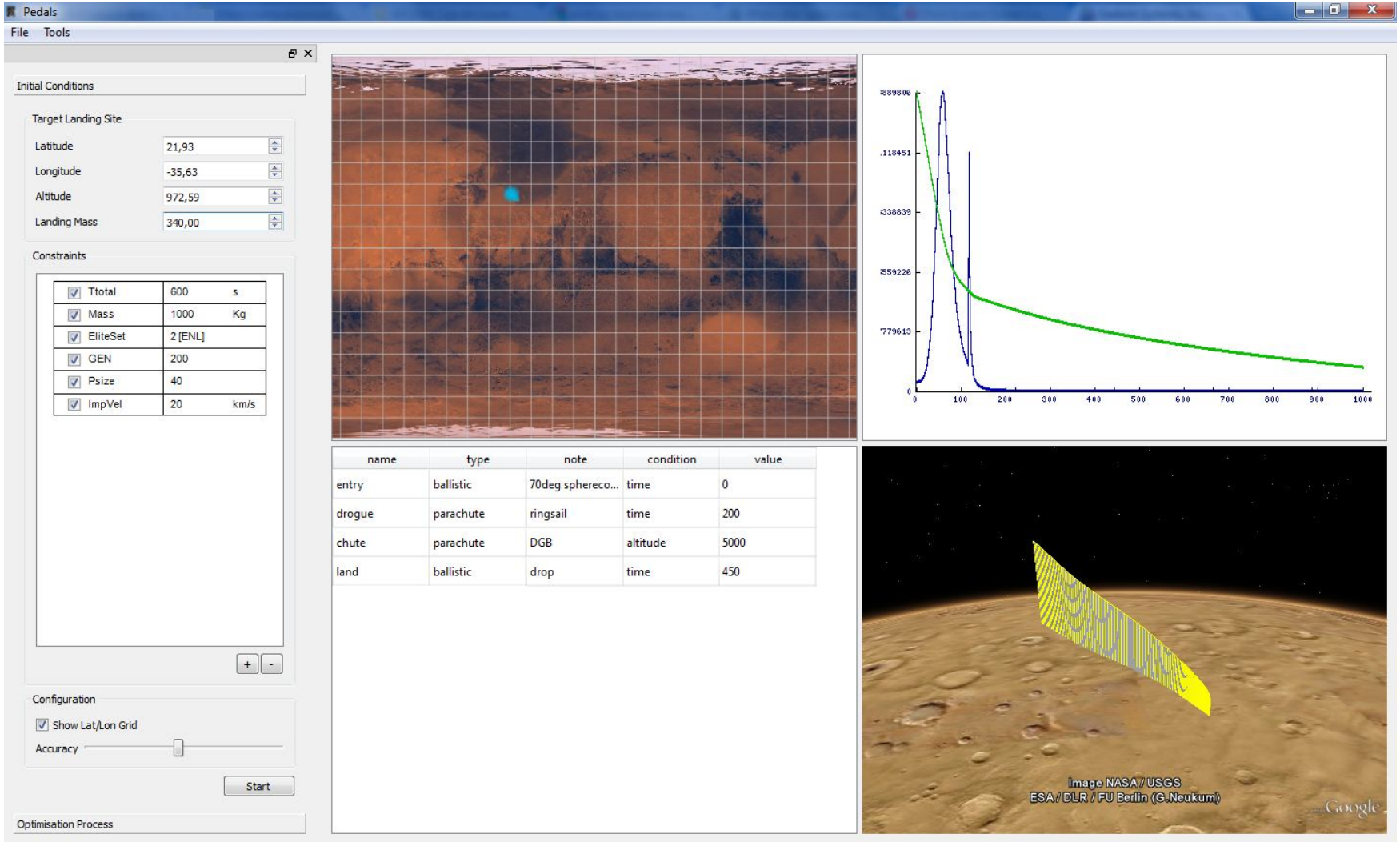
IMPLEMENTATION

BLOCK	INPUT	OUTPUT	DEV
Front-End GUI	Individual and population level data	Controls, visualisation	Qt + GoogleMars
Optimisation Engine	Performance metrics	New candidate solutions	F90
Decoder	Encoded individual candidate solution	Flight phase specification file	Perl
Trajectory Simulator	Flight phase file	Trajectory file & database, performance metrics	Perl/F90
KML Generator	Trajectory file	KML trajectory file	Perl
Models	Position	Surface elevation (MOLA); ρTP (Mars-GRAM)	
Database	All data	All data	MySQL

Outer loop (design trades)

Inner loop (single design)

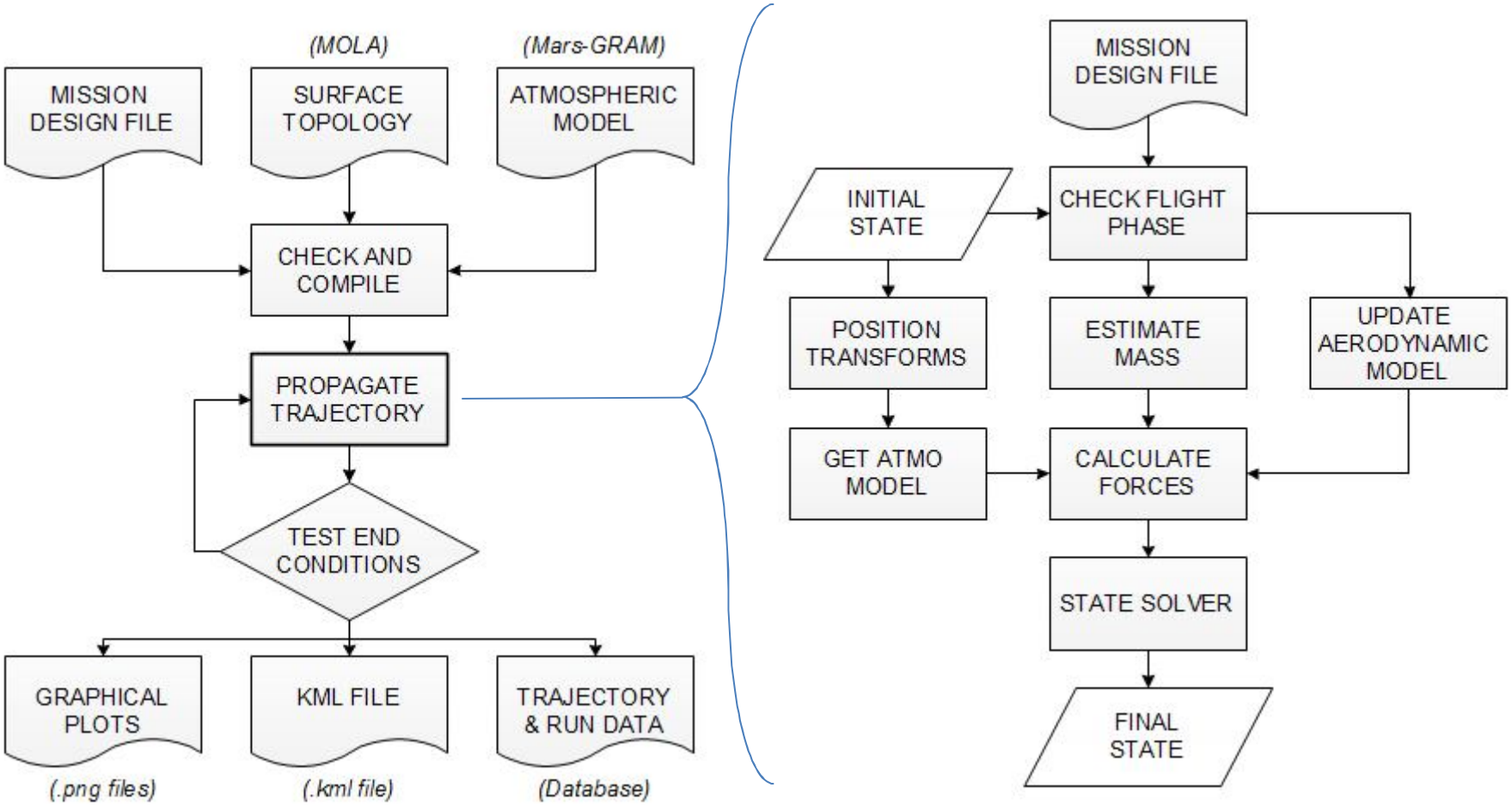
FRONT-END


Pedals
File
Tools
Initial Conditions
Target Landing Site
Latitude 21,93
Longitude -35,63
Altitude 972,59
Landing Mass 340,00
Constraints
Ttotal 600 s
Mass 1000 Kg
EliteSet 2 [ENL]
GEN 200
Psize 40
ImpVel 20 km/s
Configuration
Show Lat/Lon Grid
Accuracy
Start
Optimisation Process
name type note condition value
entry ballistic 70deg sphereco... time 0
drogue parachute ringsail time 200
chute parachute DGB altitude 5000
land ballistic drop time 450
Image NASA / USGS
ESA / DLR / FU Berlin (G.Neukum)
Google

TRAJECTORY SIM

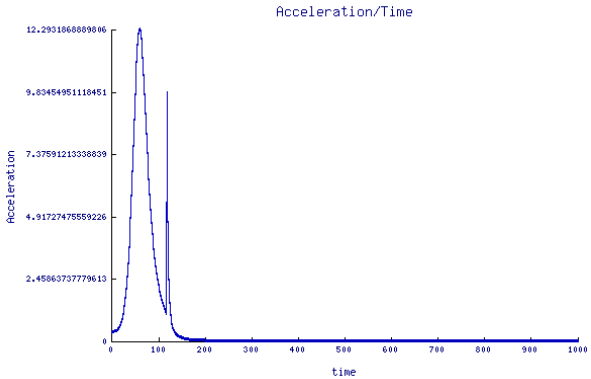
- Trajectory simulator flies mission flight phases as provided by a decoded version of the design chromosome
- Outputs (additional to trajectory points) include: range to target site, velocity and angle of impact, estimated entry mass, ...
- MOLA is used for terrain elevation, and Mars-GRAM 2010 for basic atmospheric properties through the flight
- No CFD, no 6DOF, very simplified design (but fast – around 4 full trajectory simulations per second on 'vanilla' PC)
- Overall design allows multiple simulators running anywhere to be integrated (even of different types)

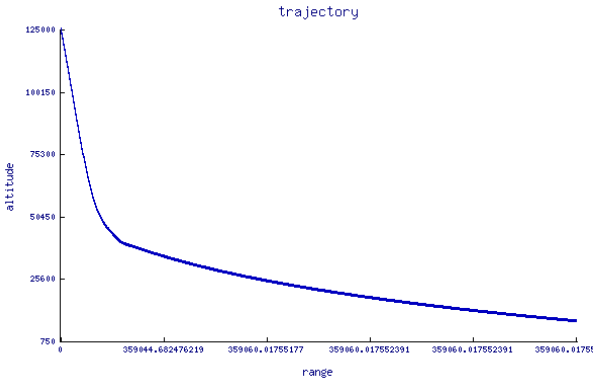
INTERNALS

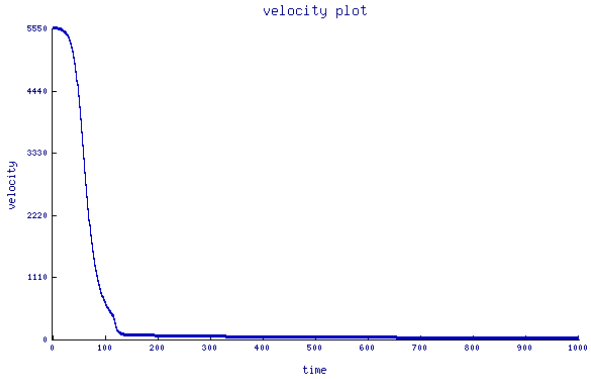

(MOLA)
(Mars-GRAM)
MISSION DESIGN FILE
SURFACE TOPOLOGY
ATMOSPHERIC MODEL
CHECK AND COMPILE
PROPAGATE TRAJECTORY
TEST END CONDITIONS
GRAPHICAL PLOTS
KML FILE
TRAJECTORY & RUN DATA
(.png files)
(.kml file)
(Database)
MISSION DESIGN FILE
INITIAL STATE
CHECK FLIGHT PHASE
POSITION TRANSFORMS
ESTIMATE MASS
UPDATE AERODYNAMIC MODEL
GET ATMO MODEL
CALCULATE FORCES
STATE SOLVER
FINAL STATE

TESTING & RESULTS

- Evolutionary optimiser adapted from other projects
- Trajectory simulator: testing ongoing with reference mission designs (collaborations/help welcomed!)
- Outstanding issues: the assumptions made so far give anomalous trajectories compared to real data, especially in range (and flight time)
- Thrusting and active turn routines are ‘buggy’: not yet ready for this audience (!)







NEXT STEPS

- Reduce the assumptions list (increase realism in trajectory code)
- Refactor code; enable support for parallel simulation services
- Include aerothermal code to check thermal constraint violation (designs that vaporise will receive low ranking)
- Move to 6DOF and improve overall aero modelling
- Perform more validation against known missions
- Improve ballute modelling
- Investigate designs near the ‘unpopular’ parts of the tradespace that appear to work
- Introduce spread operators into selection routine to ensure biodiversity in the non-dominated front

REFERENCES

- K. F. Man, K. S. Tang, and S. Kwong, “Genetic Algorithms: Concepts and Applications in Engineering Design,” IEEE Trans. Industrial Electronics, 43-5, pp. 519–534, 1996.
- B. Raiszadeh and E. M. Queen, “Partial validation of multibody program to optimize simulated trajectories II (POST II) parachute simulation with interacting forces,” Hampton, Virginia, NASA TM-2002-211634, 2002.
- D. Smith, G. Neumann et al., Mars Global Surveyor Laser Altimeter Mission Experiment Gridded Data Record, NASA Planetary Data System (MGS-M-MOLA-5-MEGDR-L3-V1.0), 2003.
- H. L. Justh, C. G. Justus, and H. S. Ramey, “Mars-Gram 2010: Improving the Precision of Mars-Gram,” in Mars Atmosphere: Modelling and observation, 2011, vol. 1, p. 265–267.
- M. Munk, “Overview of the NASA Entry, Descent and Landing Systems Analysis (EDL-SA),” IPPW-7, Barcelona, Spain, 2010.
- V. Coverstone-Carroll, J. W. Hartmann, and W. J. Mason, “Optimal multi-objective low-thrust spacecraft trajectories,” Computer methods in applied mechanics and engineering, vol. 186, no. 2-4, p. 387–402, 2000.
- J. D. Lohn, D. S. Linden, G. S. Hornby, W. F. Kraus, and A. Rodriguez-Arroyo, “Evolutionary design of an X-band antenna for NASA’s space technology 5 mission,” 2003.
- T. L. Holst and T. H. Pulliam, “Genetic Algorithm Aerodynamic Shape Optimization,” NASA Aerospace Technology Enterprise, pp.83-84, 2002.
- R. H. Dinger, “Engineering design optimization with genetic algorithms,” in Northcon/98 Conference Proceedings, 1998, p. 114–119.