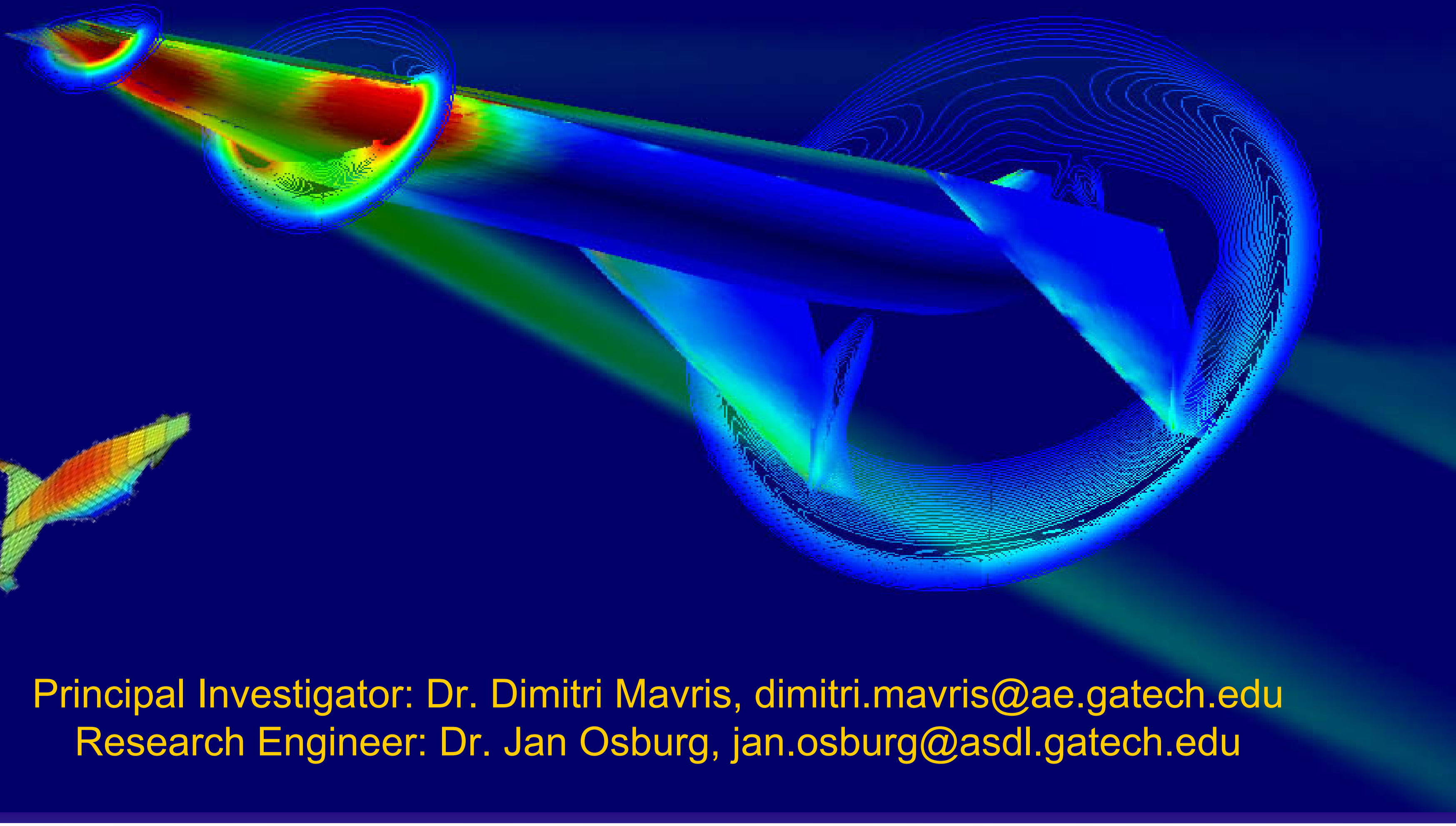
Hypersonics Research at ASDL



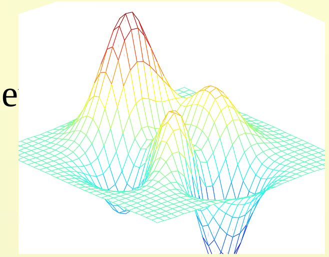
Principal Investigator: Dr. Dimitri Mavris, dimitri.mavris@ae.gatech.edu
Research Engineer: Dr. Jan Osburg, jan.osburg@asdl.gatech.edu

Overview

- RASAC: First-order hypersonic vehicle sizing code
- Design projects
  - Support of TBCC analysis effort
  - Design of morphing hypersonic strike vehicle
- New tools
  - High-Mach aerodynamics analysis environment
  - Interactive 3D trajectory visualization

RASAC First-Order Code

- Objective: rapid-turnaround hypersonic and launch vehicle modeling, sizing, simulation and analysis
- Possible alternative approaches:
  - Creation of meta-models of available legacy codes
    - Ineffective for high order and discontinuous design spaces with se
    - Does not enable “apples to apples” comparison
    - Introduces unknown assumptions from legacy codes



  - Parallel computing with actual legacy codes
    - Computational cost prohibitive
    - Code bugs/peculiarities
    - Does not enable “apples to apples” comparison
    - Still unknown assumptions from legacy codes
  - Creation of a new architecture selection approach and development of a new launch vehicle sizing and synthesis model
    - Use of top-level disciplinary models
    - “Apples to apples” comparison
    - Faster computation time
    - Assumption: Lower fidelity models can still properly represent the design space of launch vehicles for architecture selection purposes

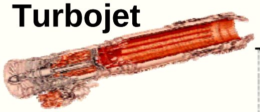
RASAC: Capabilities

Vertical takeoff
Horizontal takeoff

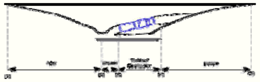
Airbreathing trajectory
Rocket trajectory

Trajectory

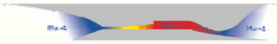
Turbojet



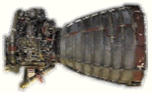
TBCC



Ramjet

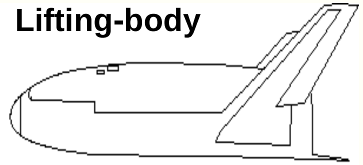


Rocket



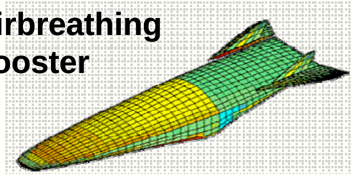
Propulsion

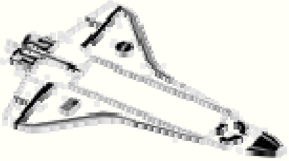
Lifting-body



All-body

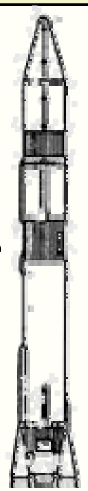
Airbreathing booster





Winged-body

Cylindrical



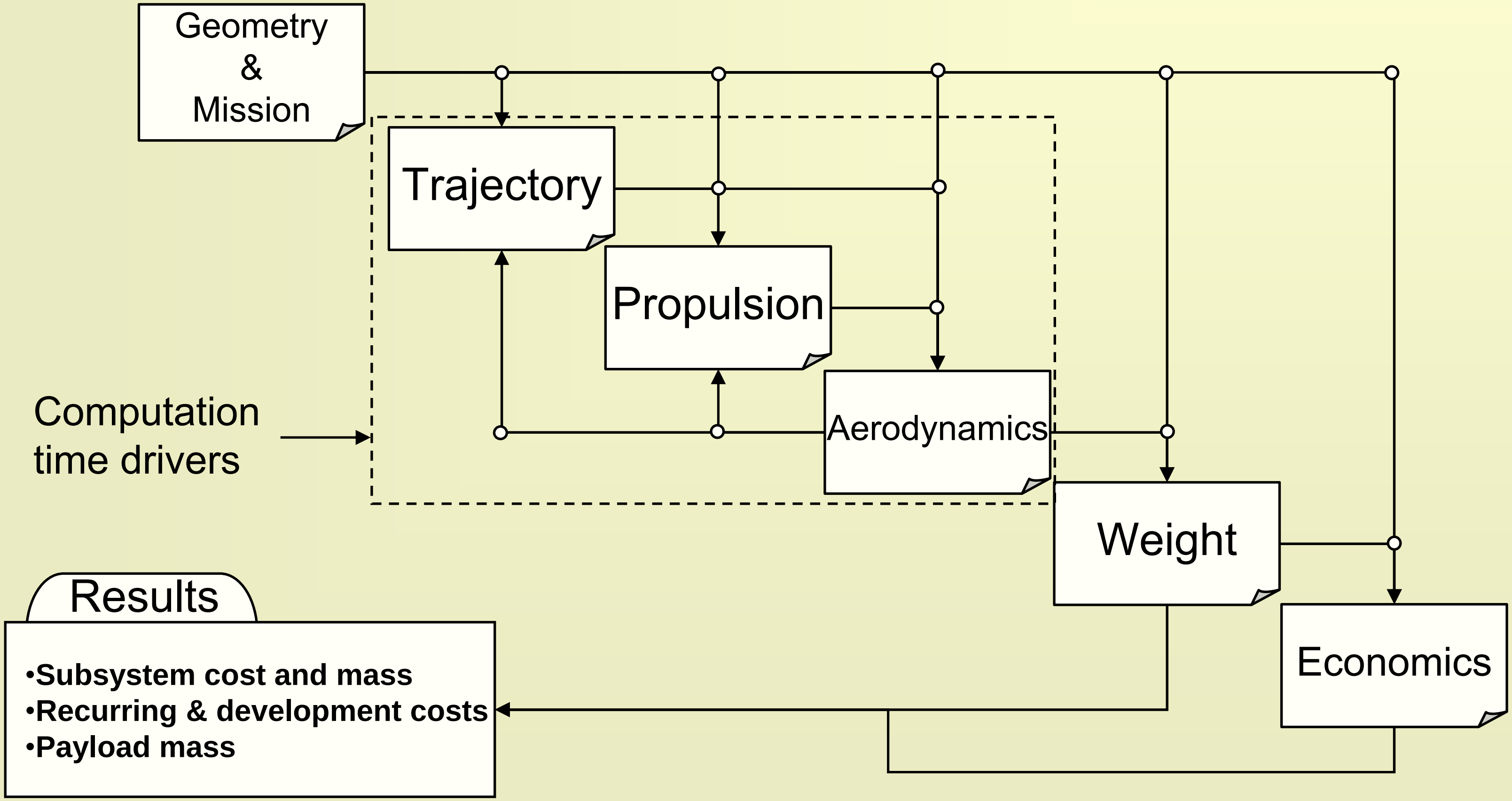
Weight

Aerodynamics

Rapid Access-to-Space Analysis Code (RASAC)

RASAC: Code Structure

- Matlab-based
- Include 5 disciplines, a geometry module and a mission module



Geometry
&
Mission

Trajectory

Propulsion

Aerodynamics

Weight

Economics

Computation
time drivers

Results

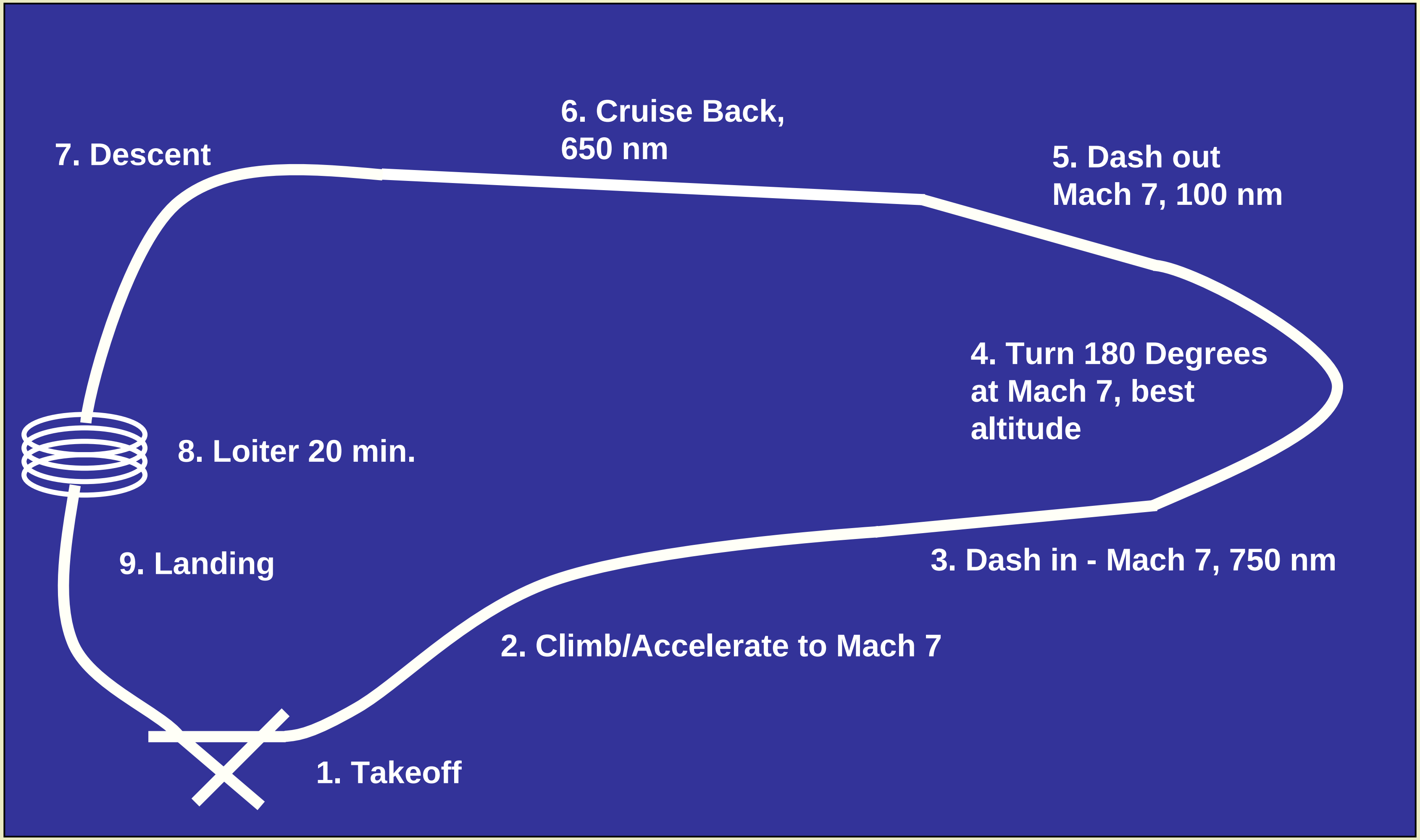
- **Subsystem cost and mass**
- **Recurring & development costs**
- **Payload mass**

Support of a TBCC Vehicle Analysis Effort

Aerospace Systems Design Laboratory
Guggenheim School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA, 30332-0150

Principal Investigator: Dr. Dimitri N. Mavris (dimitri.mavris@ae.gatech.edu)
Point of Contact: Dr. Jan Osburg (jan.osburg@asdl.gatech.edu)
Research Team: Frederic Villeneuve, Irian Ordaz, Bjorn Cole

Generic Mission



6. Cruise Back, 650 nm

7. Descent

5. Dash out Mach 7, 100 nm

4. Turn 180 Degrees at Mach 7, best altitude

8. Loiter 20 min.

9. Landing

3. Dash in - Mach 7, 750 nm

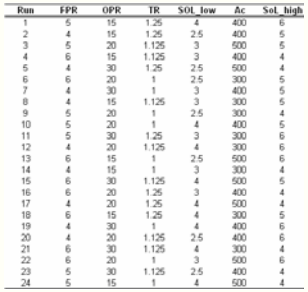
2. Climb/Accelerate to Mach 7

1. Takeoff

Design Space Exploration Approach

Design space exploration approach for the determination of the optimal engine and mission parameter settings

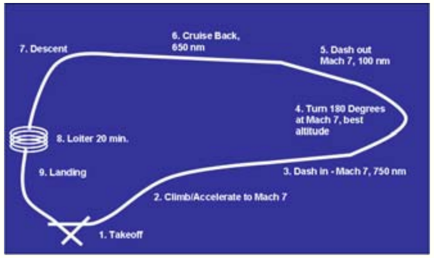
Design of Experiments (Engine Parameters)



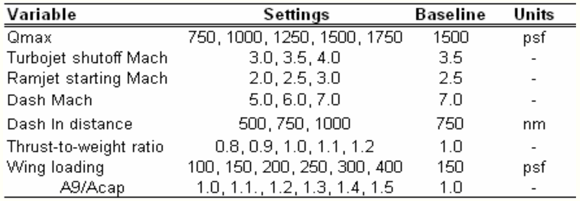
Run	FPR	OPR	TR	SOL_low	Ac	Sol_high
1	5	15	1.25	4	400	6
2	4	15	1.25	2.5	400	5
3	5	20	1.125	3	500	5
4	6	15	1.125	3	400	4
5	4	30	1.25	2.5	500	4
6	6	20	1	2.5	300	5
7	4	30	1	3	400	5
8	4	15	1.125	3	300	5
9	5	20	1	2.5	300	4
10	5	20	1	4	400	5
11	5	30	1.25	3	300	6
12	4	20	1.125	4	300	6
13	6	15	1	2.5	500	6
14	4	15	1	3	300	4
15	6	30	1.125	4	500	5
16	6	20	1.25	3	400	4
17	4	20	1.25	4	500	4
18	6	15	1.25	4	300	5
19	4	30	1	4	400	6
20	4	20	1.125	2.5	400	6
21	6	30	1.125	4	300	4
22	6	20	1	3	500	6
23	5	30	1.125	2.5	400	4
24	5	15	1	4	500	4

Vehicle Geometry

Hypersonic Strike Mission

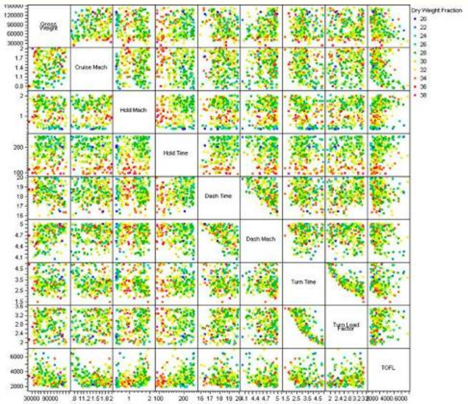


Overall Design of Experiments



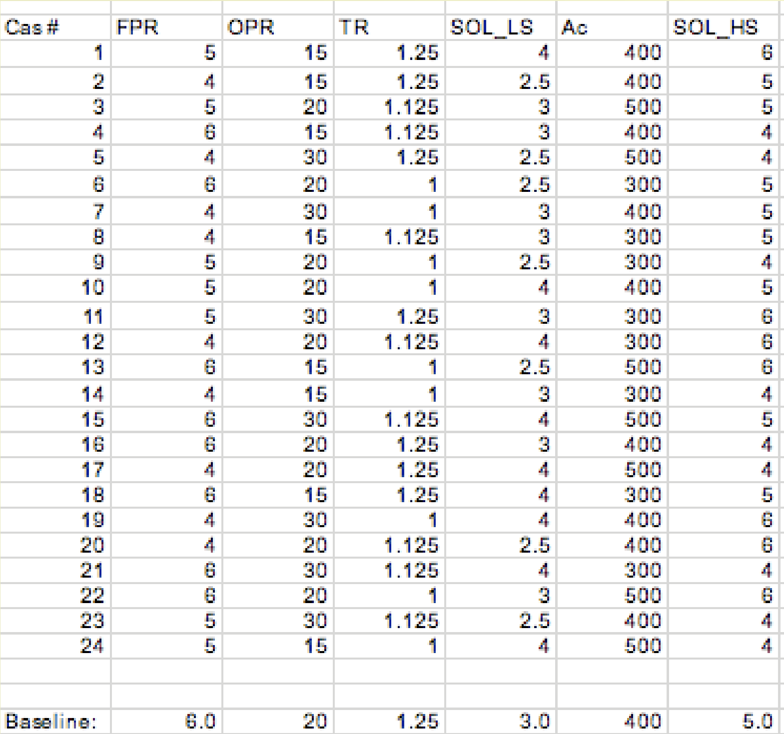
Variable	Settings	Baseline	Units
Qmax	750, 1000, 1250, 1500, 1750	1500	psf
Turbojet shutoff Mach	3.0, 3.5, 4.0	3.5	-
Ramjet starting Mach	2.0, 2.5, 3.0	2.5	-
Dash Mach	5.0, 6.0, 7.0	7.0	-
Dash In distance	500, 750, 1000	750	nm
Thrust-to-weight ratio	0.8, 0.9, 1.0, 1.1, 1.2	1.0	-
Wing loading	100, 150, 200, 250, 300, 400	150	psf
A9/Acap	1.0, 1.1., 1.2, 1.3, 1.4, 1.5	1.0	-

Design Space Exploration

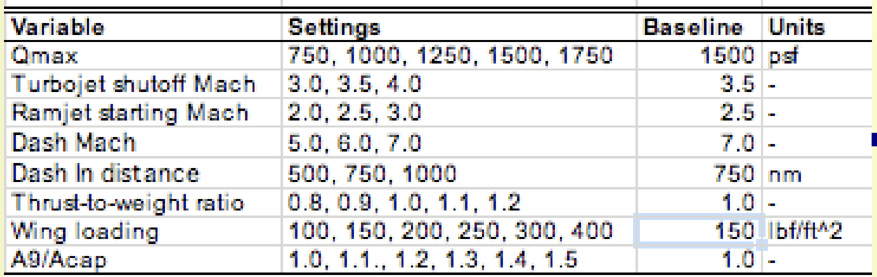


Design Space Exploration

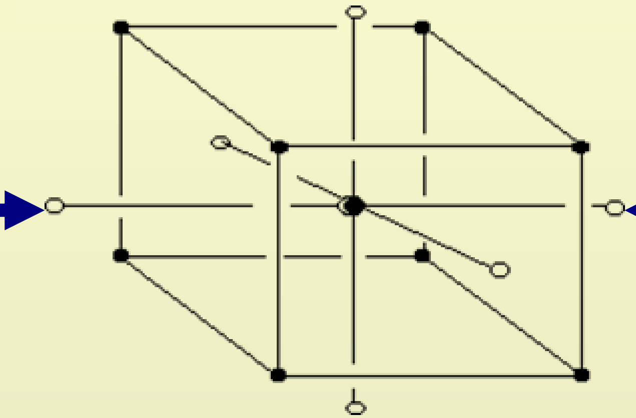
Engine Settings vs. Mission Requirements



Cas #	FPR	OPR	TR	SOL_LS	Ac	SOL_HS
1	5	15	1.25	4	400	6
2	4	15	1.25	2.5	400	5
3	5	20	1.125	3	500	5
4	6	15	1.125	3	400	4
5	4	30	1.25	2.5	500	4
6	6	20	1	2.5	300	5
7	4	30	1	3	400	5
8	4	15	1.125	3	300	5
9	5	20	1	2.5	300	4
10	5	20	1	4	400	5
11	5	30	1.25	3	300	6
12	4	20	1.125	4	300	6
13	6	15	1	2.5	500	6
14	4	15	1	3	300	4
15	6	30	1.125	4	500	5
16	6	20	1.25	3	400	4
17	4	20	1.25	4	500	4
18	6	15	1.25	4	300	5
19	4	30	1	4	400	6
20	4	20	1.125	2.5	400	6
21	6	30	1.125	4	300	4
22	6	20	1	3	500	6
23	5	30	1.125	2.5	400	4
24	5	15	1	4	500	4
Baseline:	6.0	20	1.25	3.0	400	5.0



Variable	Settings	Baseline	Units
Qmax	750, 1000, 1250, 1500, 1750	1500	psf
Turbojet shutoff Mach	3.0, 3.5, 4.0	3.5	-
Ramjet starting Mach	2.0, 2.5, 3.0	2.5	-
Dash Mach	5.0, 6.0, 7.0	7.0	-
Dash In distance	500, 750, 1000	750	nm
Thrust-to-weight ratio	0.8, 0.9, 1.0, 1.1, 1.2	1.0	-
Wing loading	100, 150, 200, 250, 300, 400	150	lbf/ft^2
A9/Acap	1.0, 1.1., 1.2, 1.3, 1.4, 1.5	1.0	-

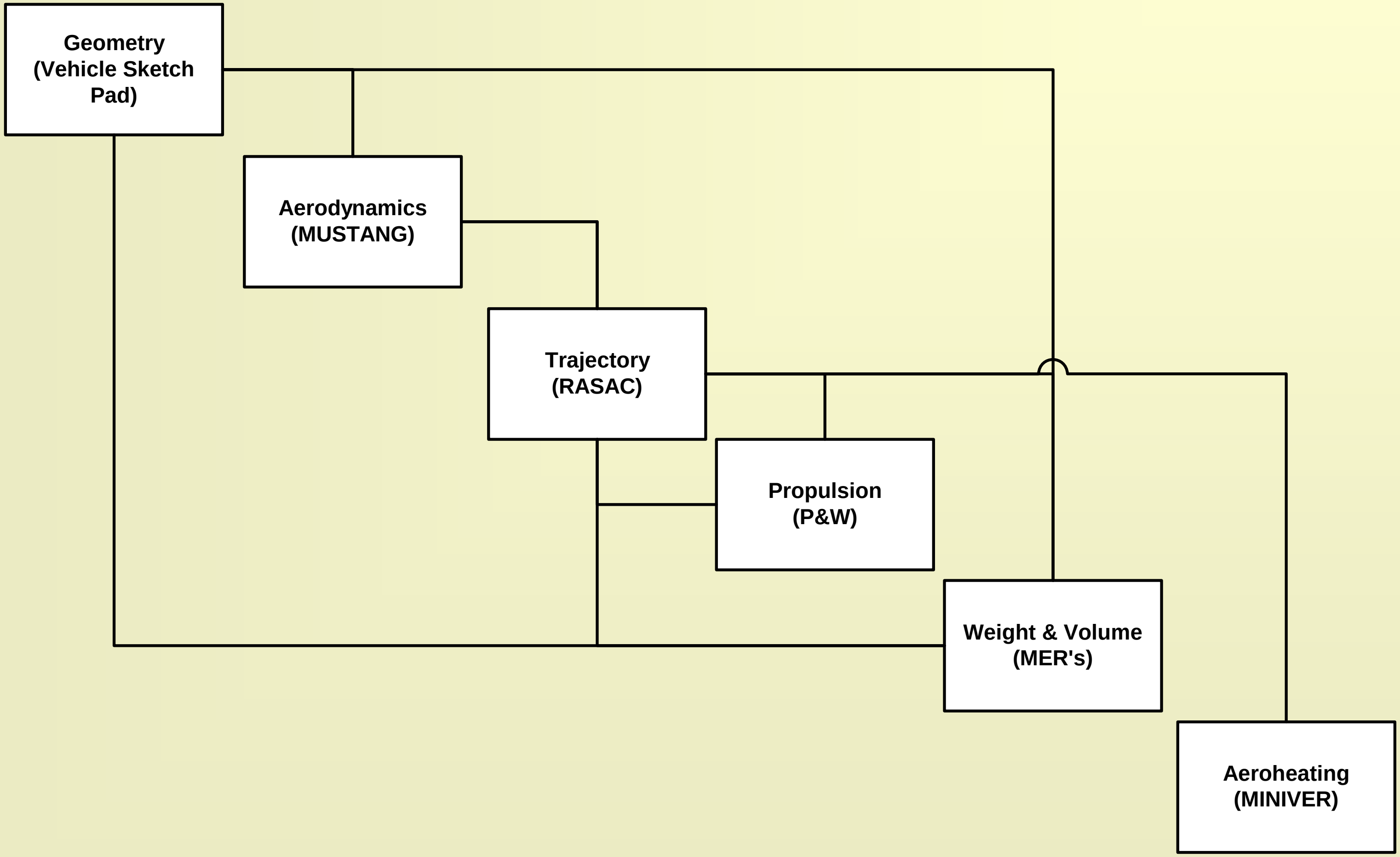


http://www.geocities.com/ResearchTriangle/System/3737/imgs/section3394.gif

- ❖ Each engine setting tested for Fractional Factorial DoE of mission requirements

Modeling & Simulation

- Design Structure Matrix



Geometry: Vehicle Sketch Pad (VSP)

3D Drawing of the baseline vehicle

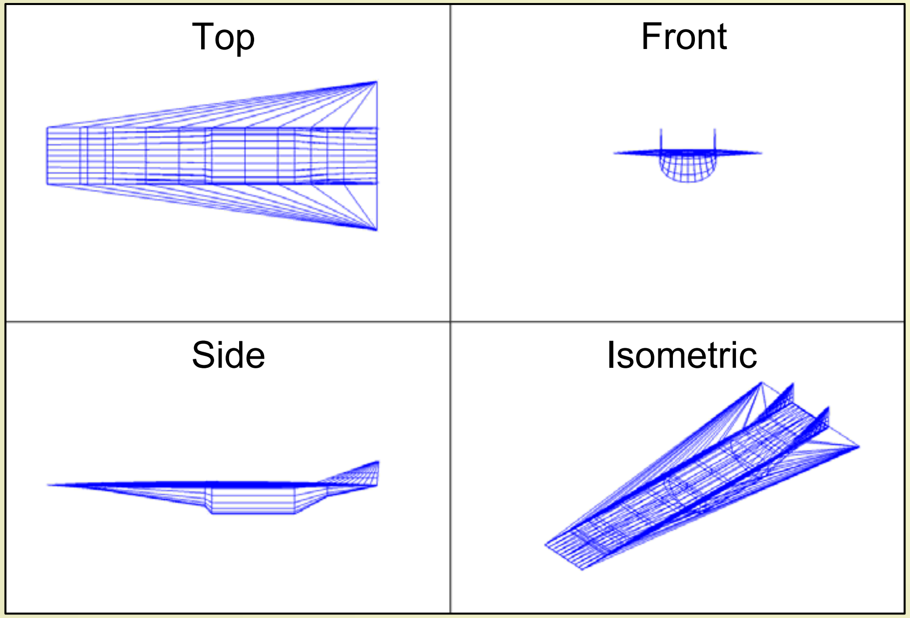
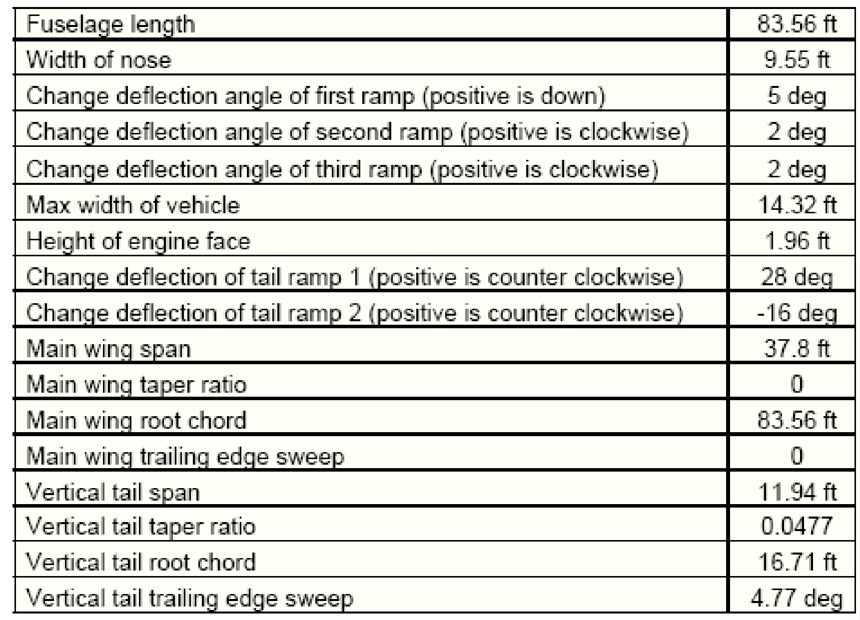


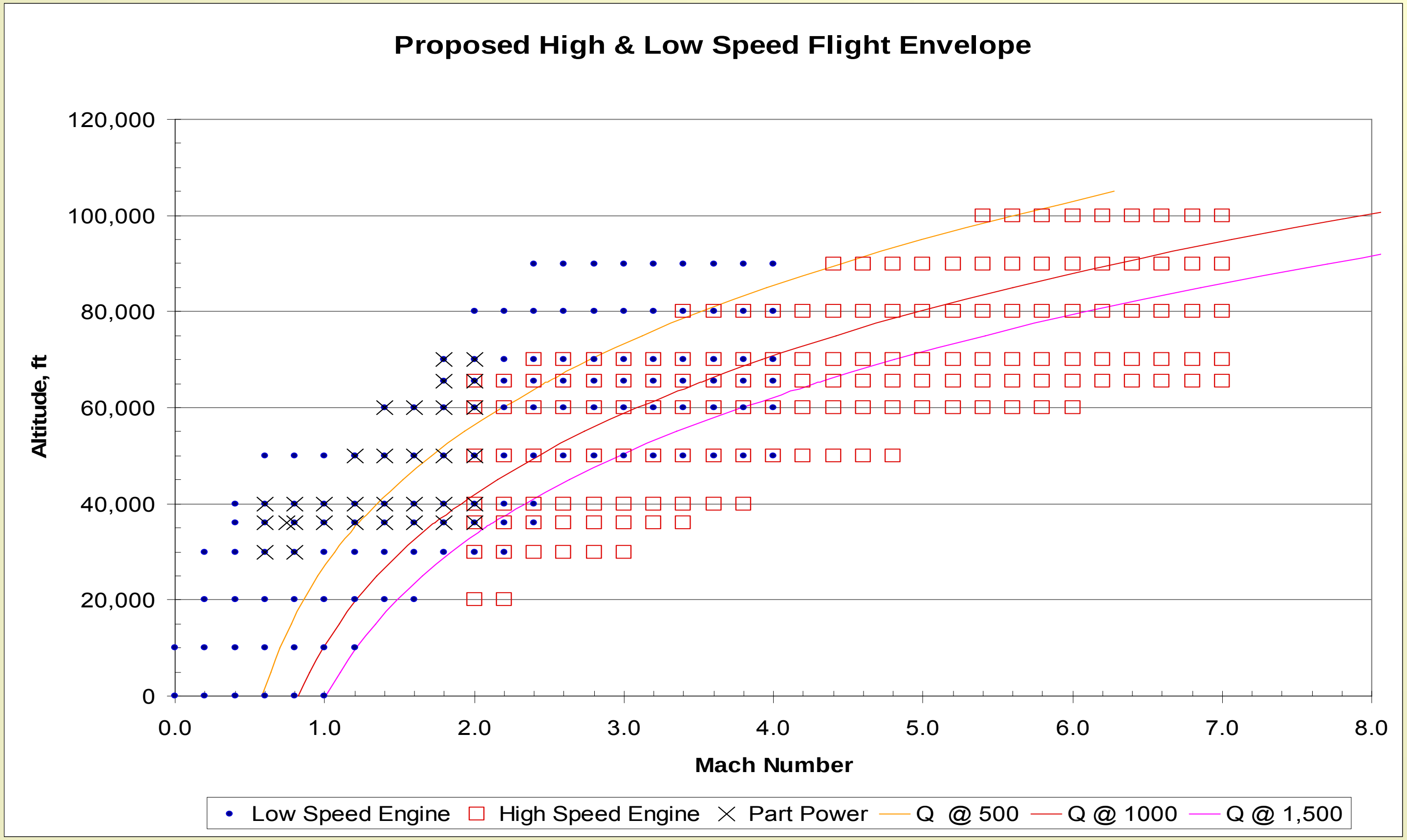
Table: Vehicle parameters and dimensions



Fuselage length	83.56 ft
Width of nose	9.55 ft
Change deflection angle of first ramp (positive is down)	5 deg
Change deflection angle of second ramp (positive is clockwise)	2 deg
Change deflection angle of third ramp (positive is clockwise)	2 deg
Max width of vehicle	14.32 ft
Height of engine face	1.96 ft
Change deflection of tail ramp 1 (positive is counter clockwise)	28 deg
Change deflection of tail ramp 2 (positive is counter clockwise)	-16 deg
Main wing span	37.8 ft
Main wing taper ratio	0
Main wing root chord	83.56 ft
Main wing trailing edge sweep	0
Vertical tail span	11.94 ft
Vertical tail taper ratio	0.0477
Vertical tail root chord	16.71 ft
Vertical tail trailing edge sweep	4.77 deg

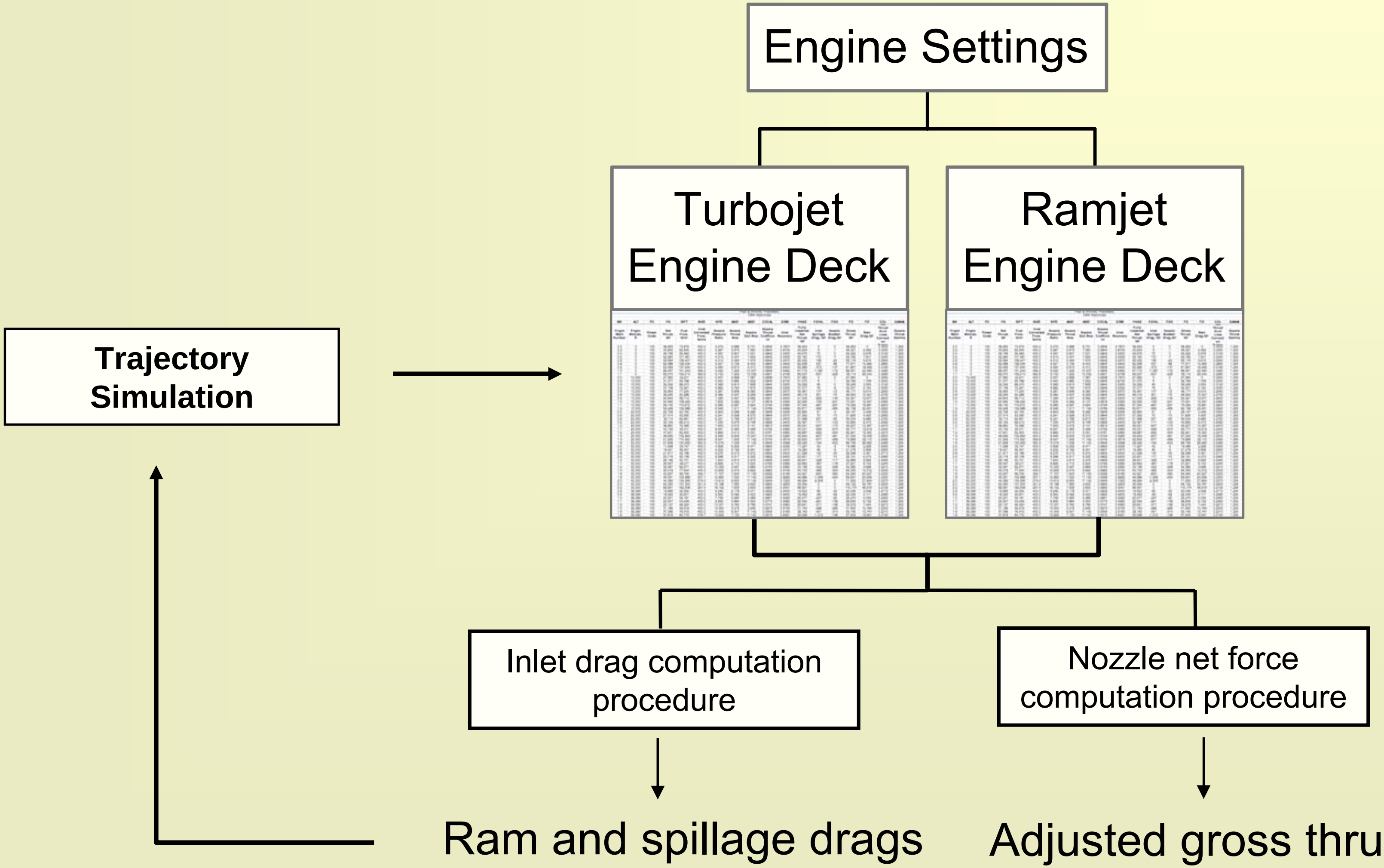
Propulsion

- Flight envelope of low- and high-speed engines



Propulsion

- Drag and thrust calculation workflow



Engine Settings

Turbojet Engine Deck

Ramjet Engine Deck

Trajectory Simulation

Inlet drag computation procedure

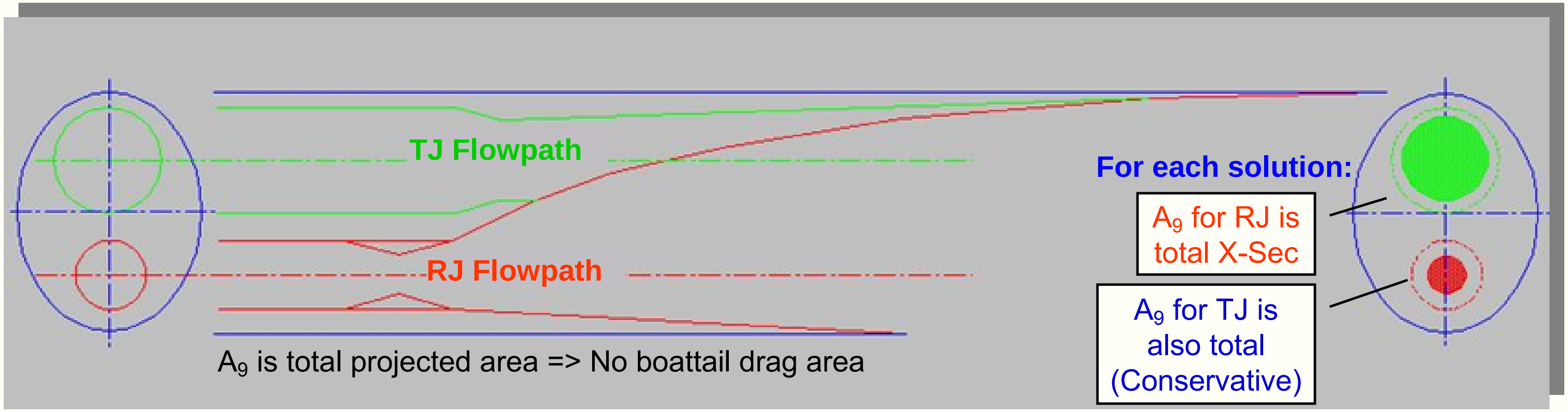
Nozzle net force computation procedure

Ram and spillage drags

Adjusted gross thrust

Over-Under Geometry Adapted to Vehicle

Comparison with Original GT Vehicle to Define Nozzle A_9 Areas



TJ Flowpath

RJ Flowpath

A_9 is total projected area => No boattail drag area

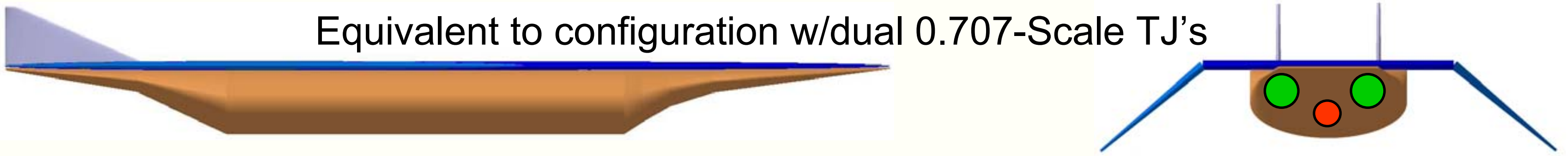
For each solution:

A_9 for RJ is total X-Sec

A_9 for TJ is also total (Conservative)

Modified Architecture to Satisfy Single TJ Study

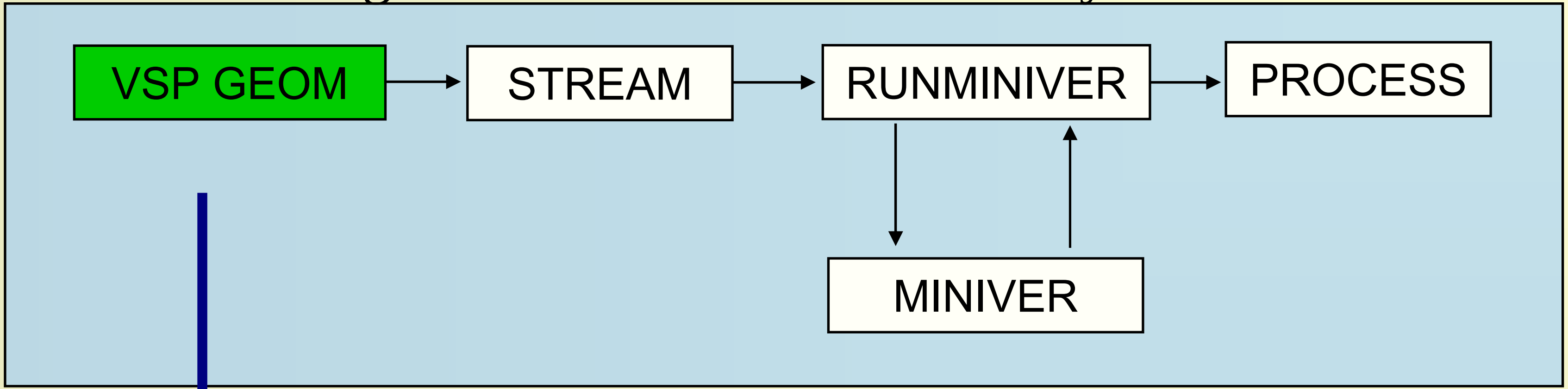
Equivalent to configuration w/dual 0.707-Scale TJ’s



Original GT Architecture better suited to dual TJ Installation

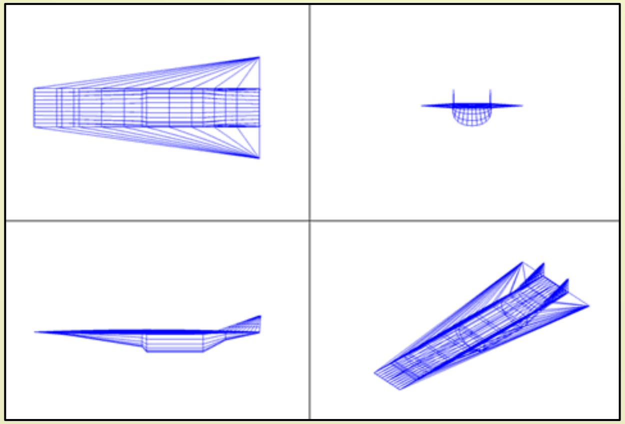
Aerothermal Analysis Process

- Process Diagram of the Aerothermal Analysis



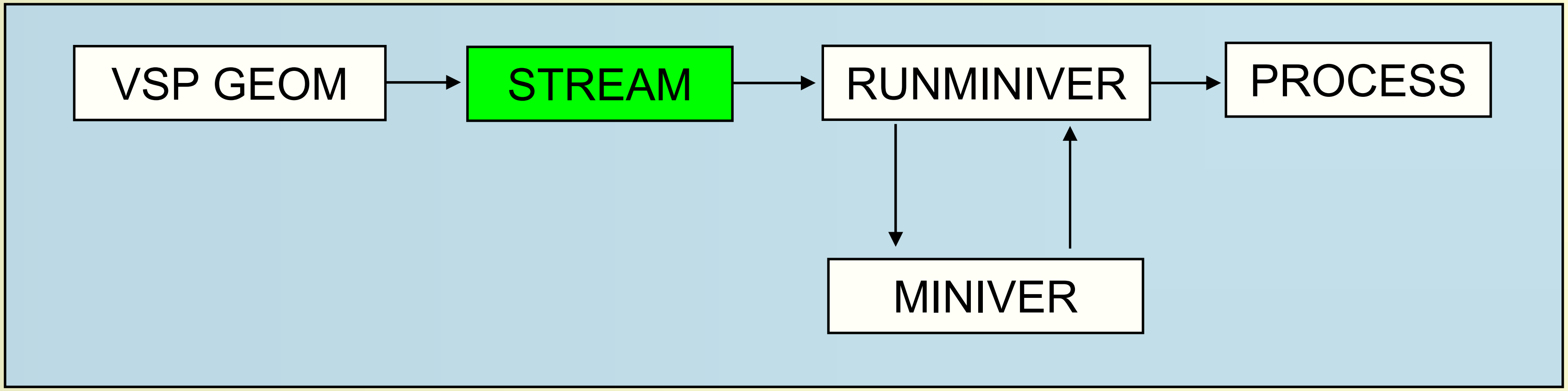
VSP GEOM → STREAM → RUNMINIVER → PROCESS

RUNMINIVER ⇄ MINIVER



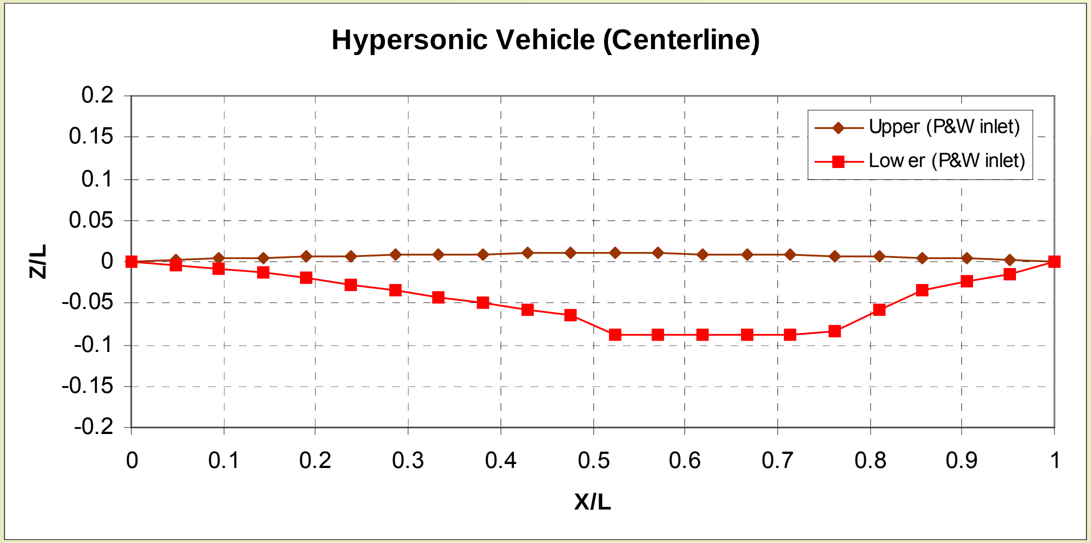
Vehicle Sketch Pad Geometry

Aerothermal Analysis Process



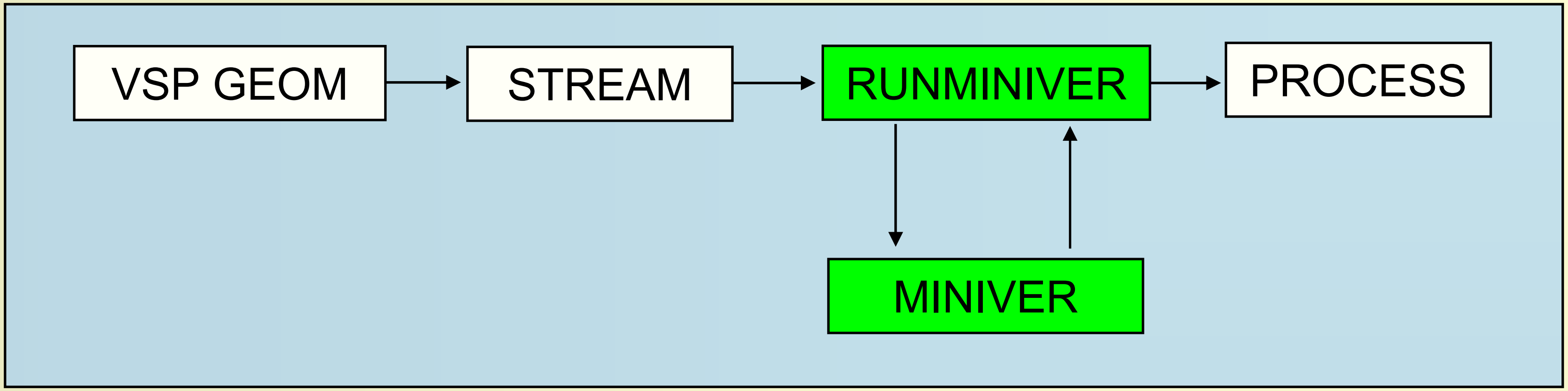
VSP GEOM → STREAM → RUNMINIVER → PROCESS

RUNMINIVER ⇄ MINIVER



- A sample streamline or contour for the fuselage centerline from the STREAM script
- These are then integrated into the MINIVER input file
- The vehicle is discretized into a number of these streamlines in the spanwise direction and mirrored on the other side assuming symmetry of the vehicle

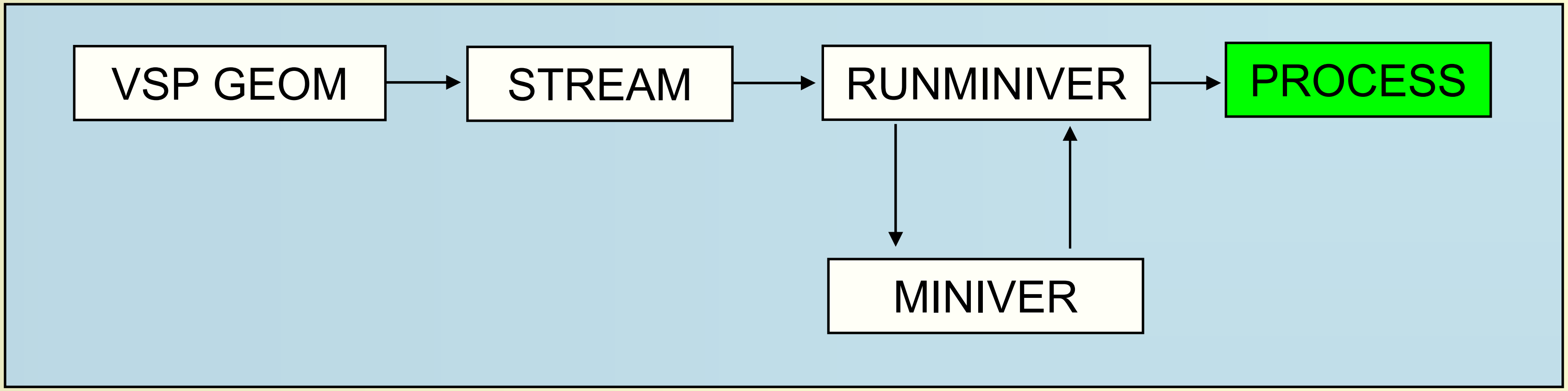
Aerothermal Analysis Process



- ‘RUNMINIVER’
  - Executes automatically MINIVER with all the input files generated by STREAM
  - Generate an input and output file for each streamline

- ‘MINIVER’
  - Aerothermal analysis code developed by NASA

Aerothermal Analysis: Output Description



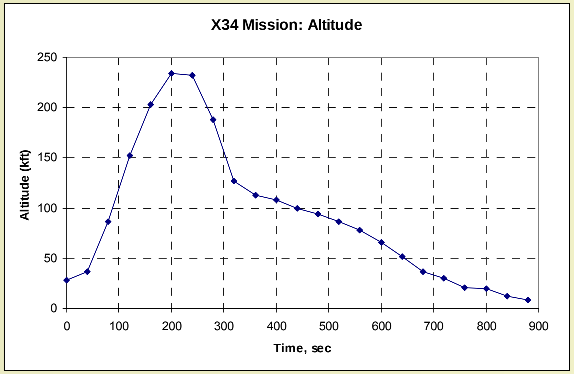
- ‘PROCESS’

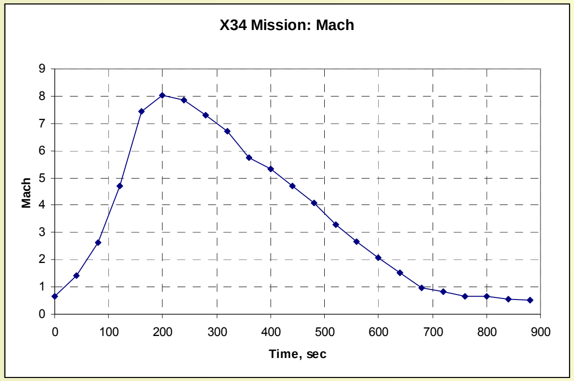
  Post-processing script gathering the …

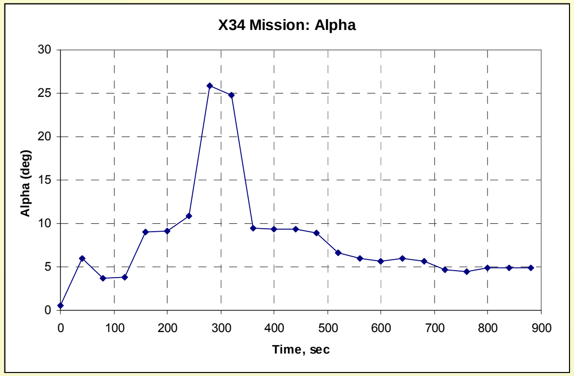
  - Heatload – Contains the average, total, peak, and minimum heatload as a function of time throughout the mission.
  - Heatrate – Contains the average, total, peak, and minimum heatrate as a function of time throughout the mission.
  - Results – Contains the detailed aerothermal results (heat coefficient, heatrate, and heatload) for each point (lengthwise and spanwise) on the vehicle at each point in the mission.
  - Heatload_Loc – Contains the peak, minimum heatload values and where they are located on the vehicle throughout the mission.
  - Heatrate_Loc – Contains the peak, minimum heatrate values and where they are located on the vehicle throughout the mission.

Aerothermal Analysis Validation Case: X-34

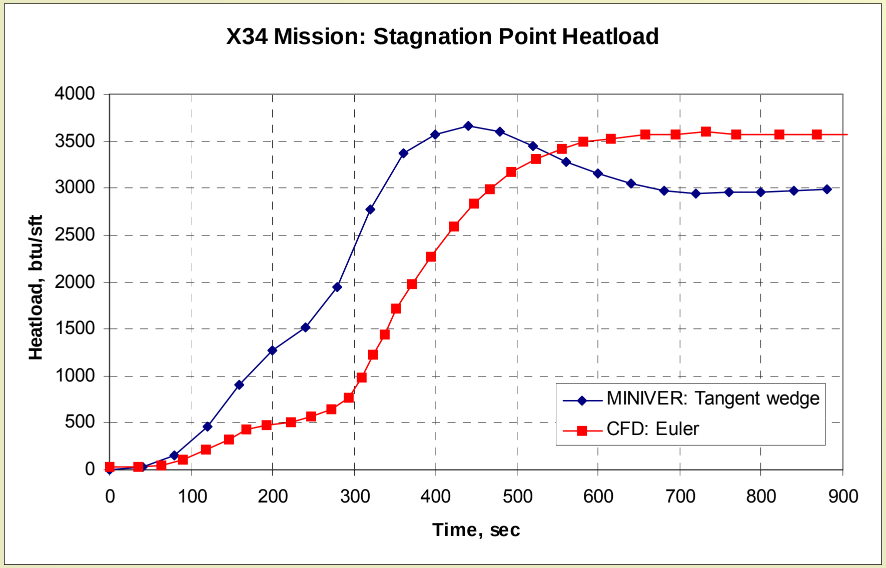
X-34 Trajectory

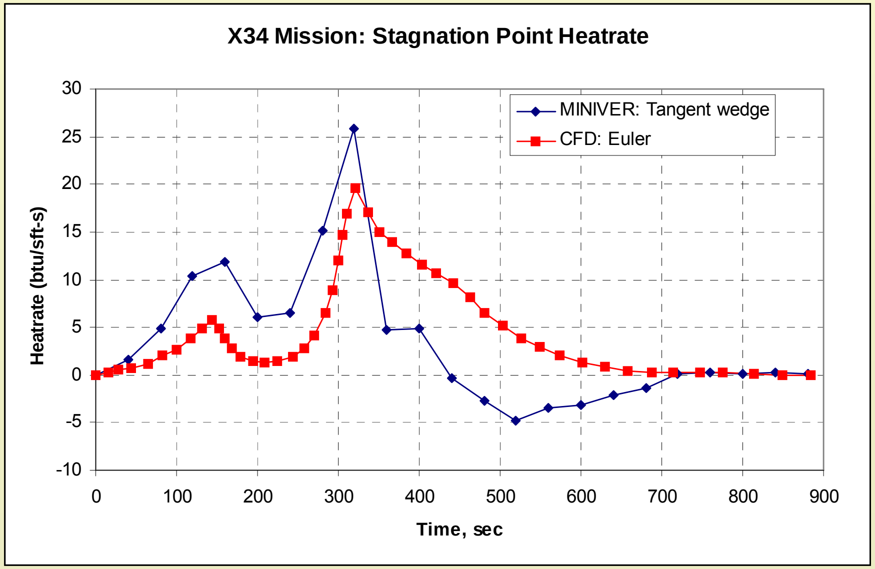

X34 Mission: Altitude


X34 Mission: Mach


X34 Mission: Alpha

Comparison of results


X34 Mission: Stagnation Point Heatload

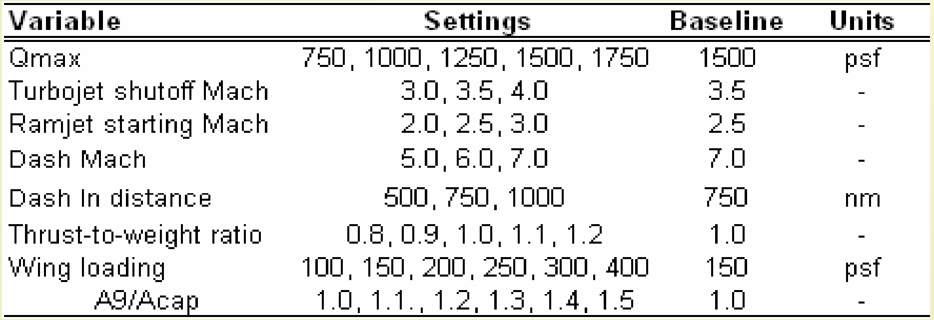

X34 Mission: Stagnation Point Heatrate

Design Space Exploration

- Mission Design of Experiments
  - Fractional Factorial
  - 360 runs & 8 variables

- Variables and settings

Mission Parameters included in the DoE



Variable	Settings	Baseline	Units
Qmax	750, 1000, 1250, 1500, 1750	1500	psf
Turbojet shutoff Mach	3.0, 3.5, 4.0	3.5	-
Ramjet starting Mach	2.0, 2.5, 3.0	2.5	-
Dash Mach	5.0, 6.0, 7.0	7.0	-
Dash In distance	500, 750, 1000	750	nm
Thrust-to-weight ratio	0.8, 0.9, 1.0, 1.1, 1.2	1.0	-
Wing loading	100, 150, 200, 250, 300, 400	150	psf
A9/Acap	1.0, 1.1., 1.2, 1.3, 1.4, 1.5	1.0	-

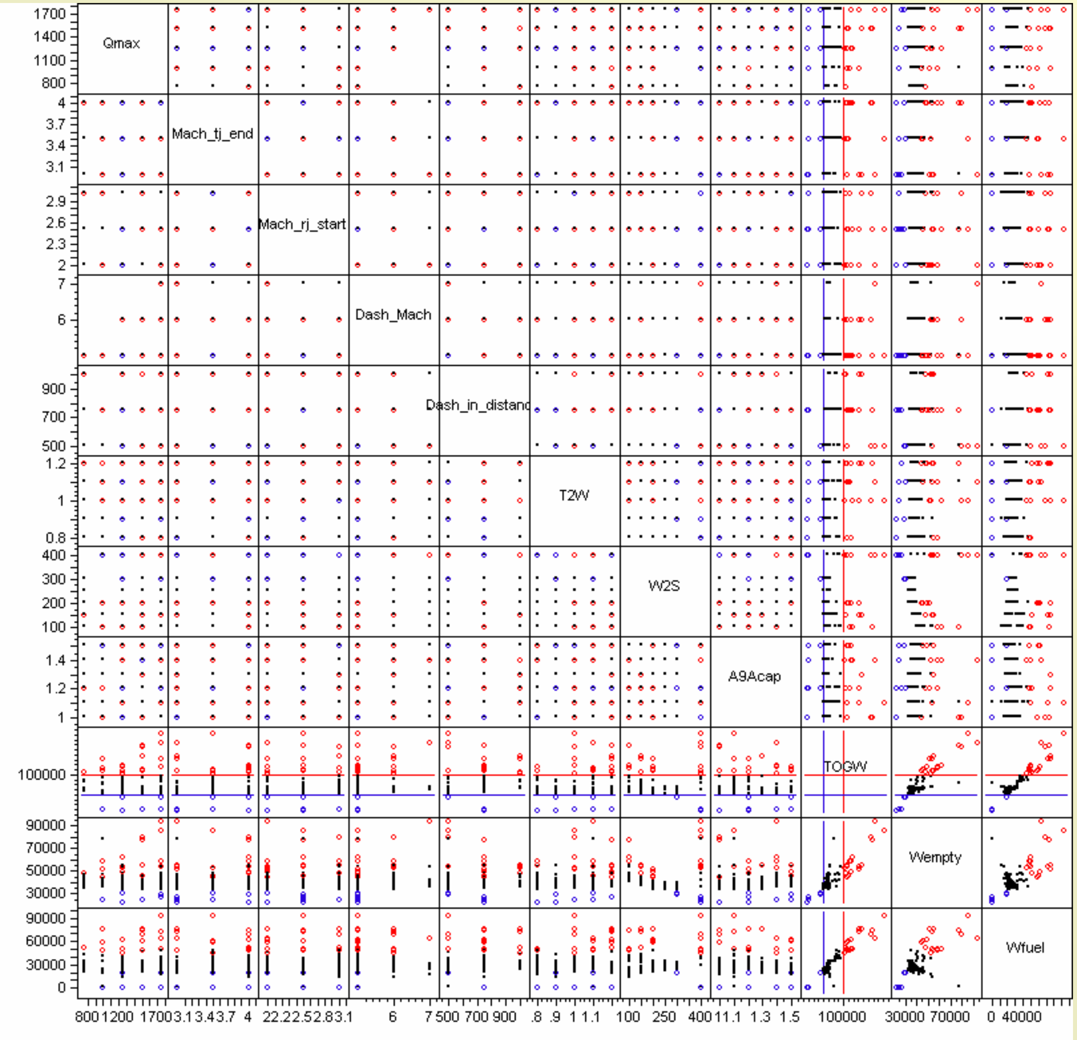
- Simulation Results
  - Running time: ~ 4hrs
  - ~40% of runs have closed vehicles

Design Space Exploration

- Multivariate analysis plot

Mission parameters

Responses

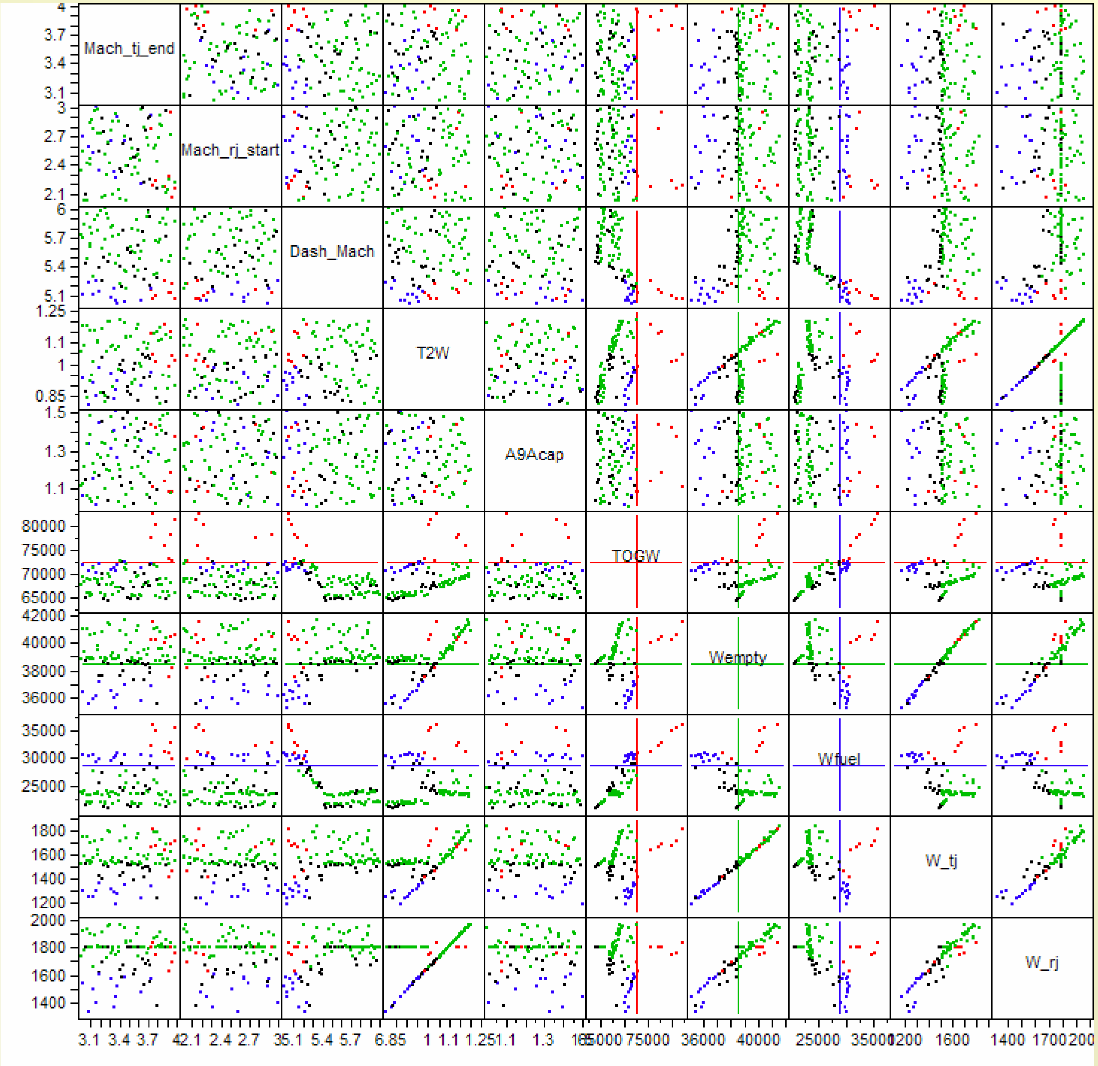


○ TOGW < 60,000 lbs

○ TOGW > 100,000 lbs

Results

- Multivariate Analysis
  - Latin Hypercube (100 runs)
- Constants:
  - W/S = 150 lb/ft^2
- Variable Ranges
  1. Mach TJ shutoff: [3, 4]
  2. Mach RJ start : [2, 3]
  3. Dash Mach : [5, 6]
  4. T/W : [0.8 1.2]
  5. A_9/A_{cap} : [1, 1.5]
- Limits:
  - Wfuel > 30 klbs (blue)
  - Wempty > 40 klbs (green)
  - TOGW > 70 klbs (red)



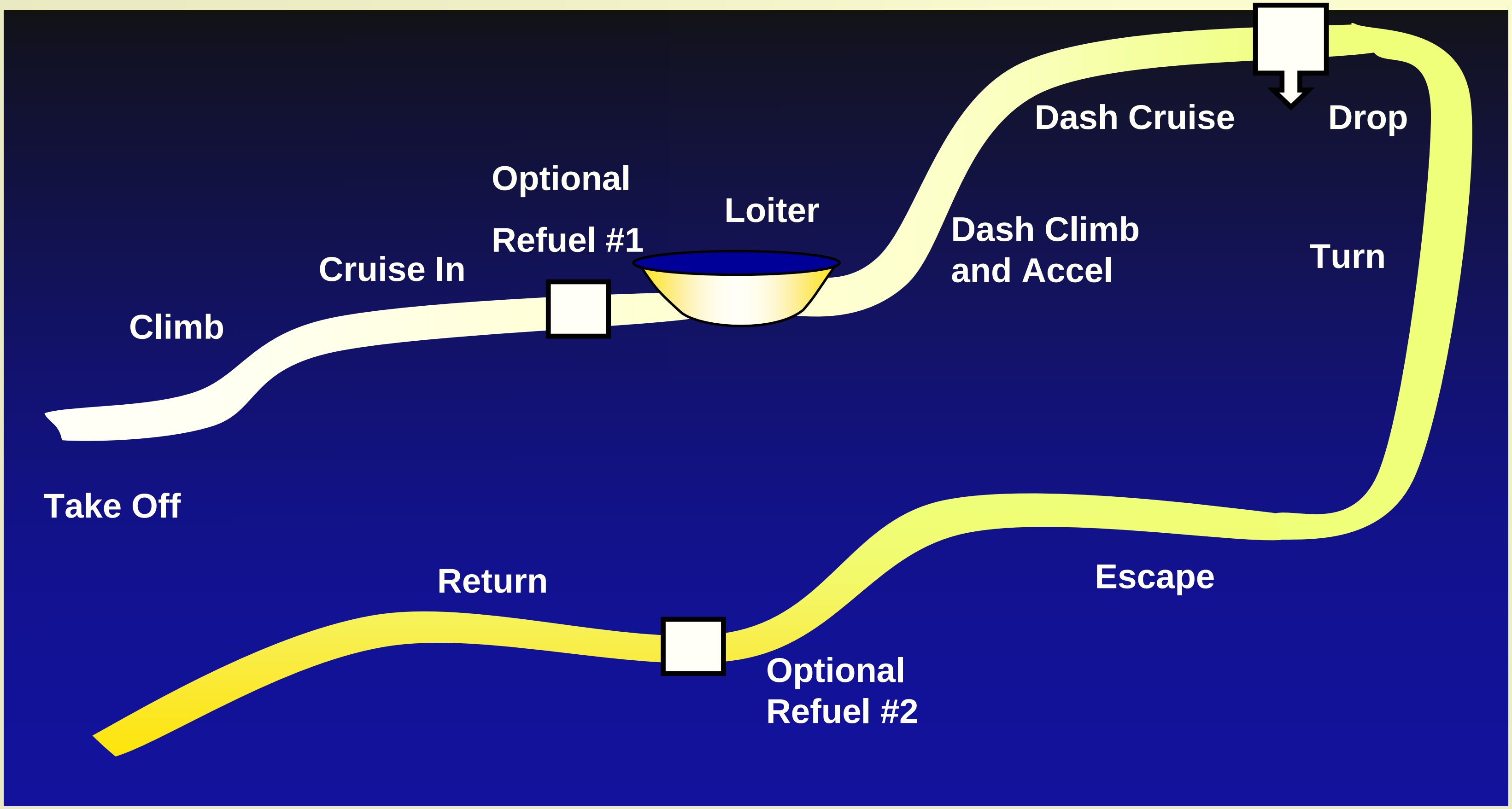
Hypersonic Persistent Configuration (HyPer) Development

WBI/AFRL Sponsored Research

Points of Contact:
Dr. Jan Osburg (jan.osburg@asdl.gatech.edu)
Dr. Peter Hollingsworth (peter.hollingsworth@ae.gatech.edu)

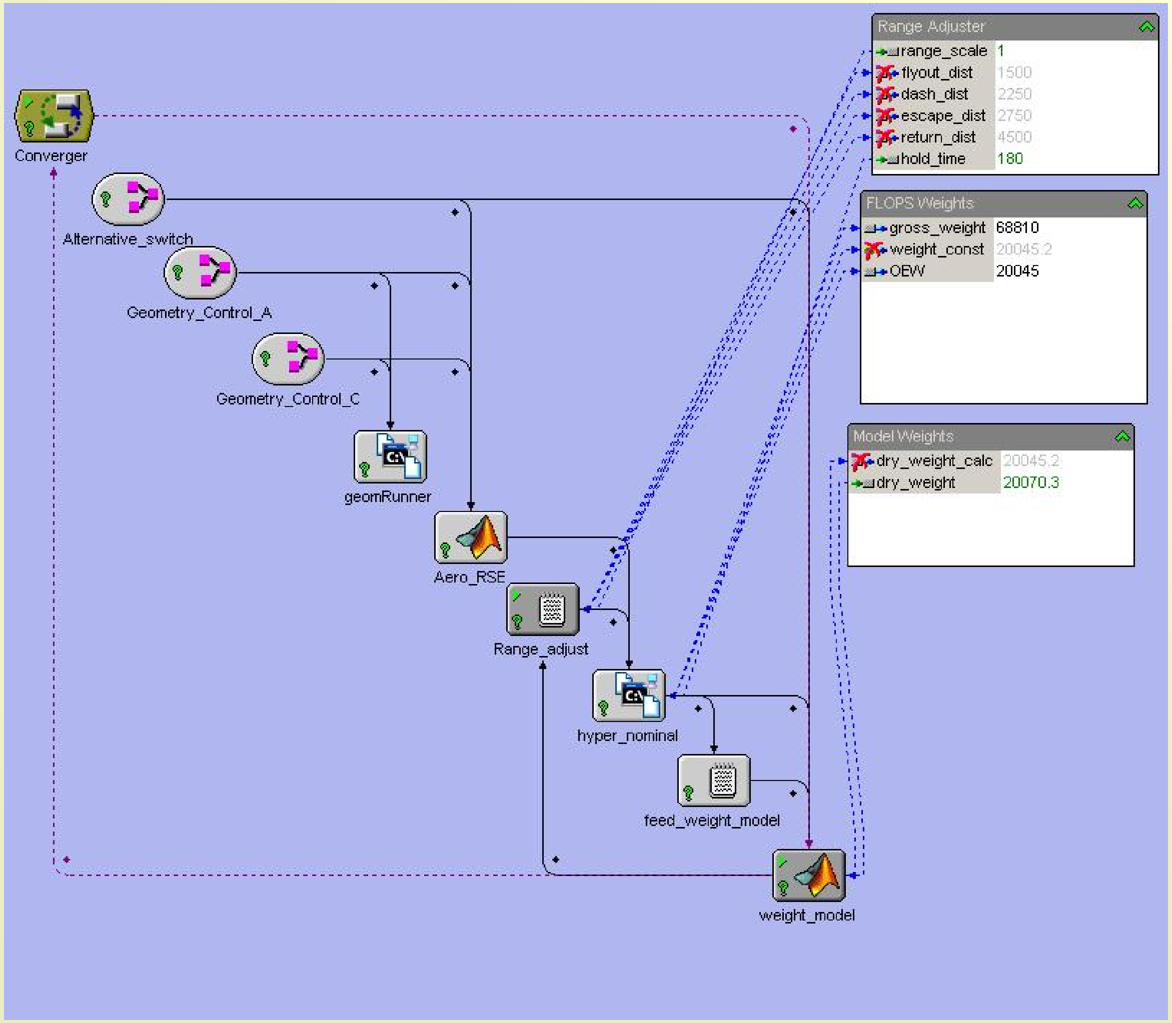
HyPer: Mission

- Dash/strike at up to Mach 5, loiter/cruise/refueling subsonic
- Sizing (ModelCenter/FLOPS) based on “rubber mission,” shown below
- Sponsor desires morphing configuration



FLOPS Sizing Environment

- Designed to converge weights input into FLOPS and computed from weights model
- Aerodynamic RSEs are integrated in loop
- Incorporates propulsion tables
- Able to run alternate geometries
  - Folding wingtips (XB-70 style)
  - Variable-sweep wing



Range Adjuster

range_scale	1
flyout_dist	1500
dash_dist	2250
escape_dist	2750
return_dist	4500
hold_time	180

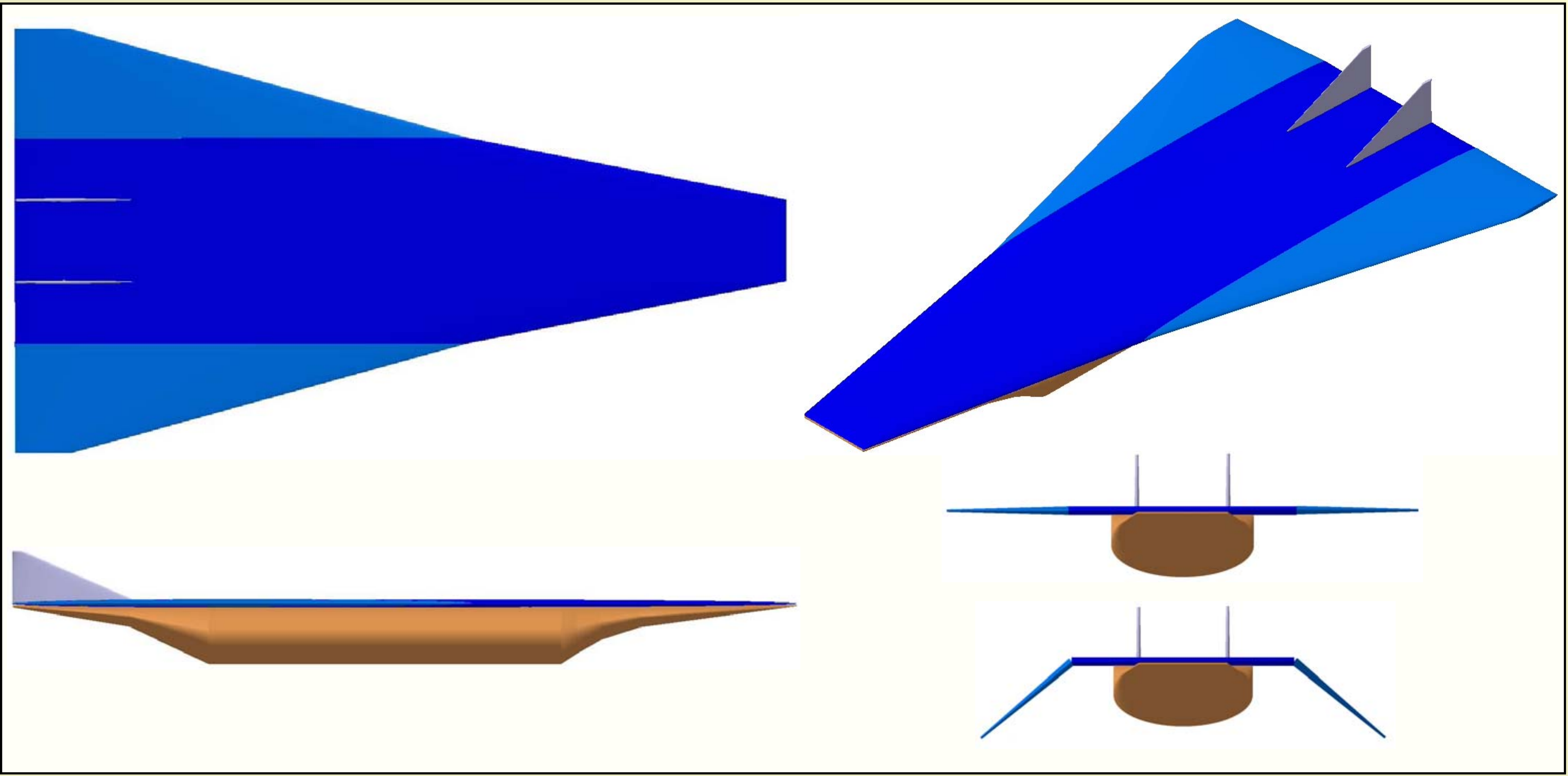
FLOPS Weights

gross_weight	68810
weight_const	20045.2
OEW	20045

Model Weights

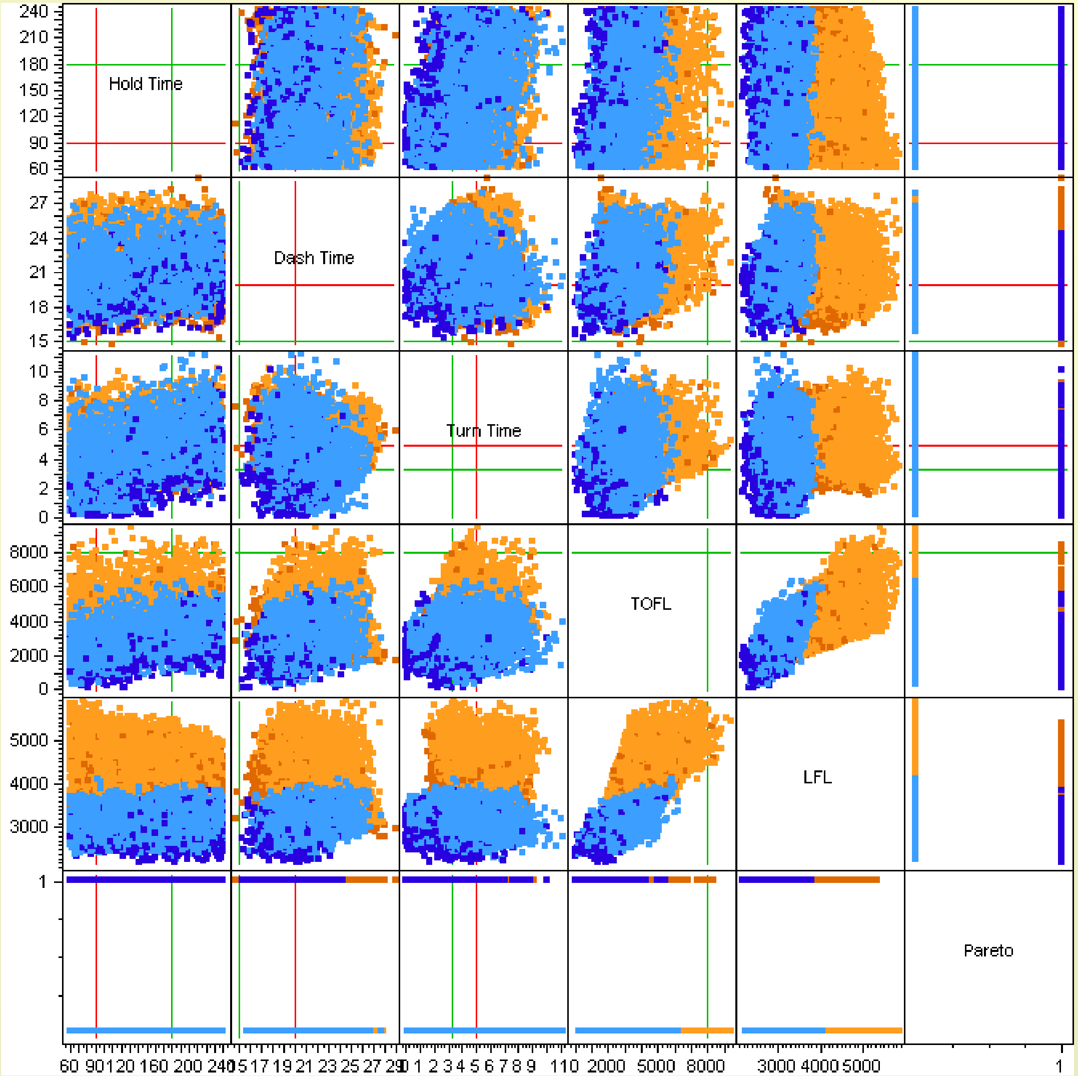
dry_weight_calc	20045.2
dry_weight	20070.3

Geometry – One Configuration

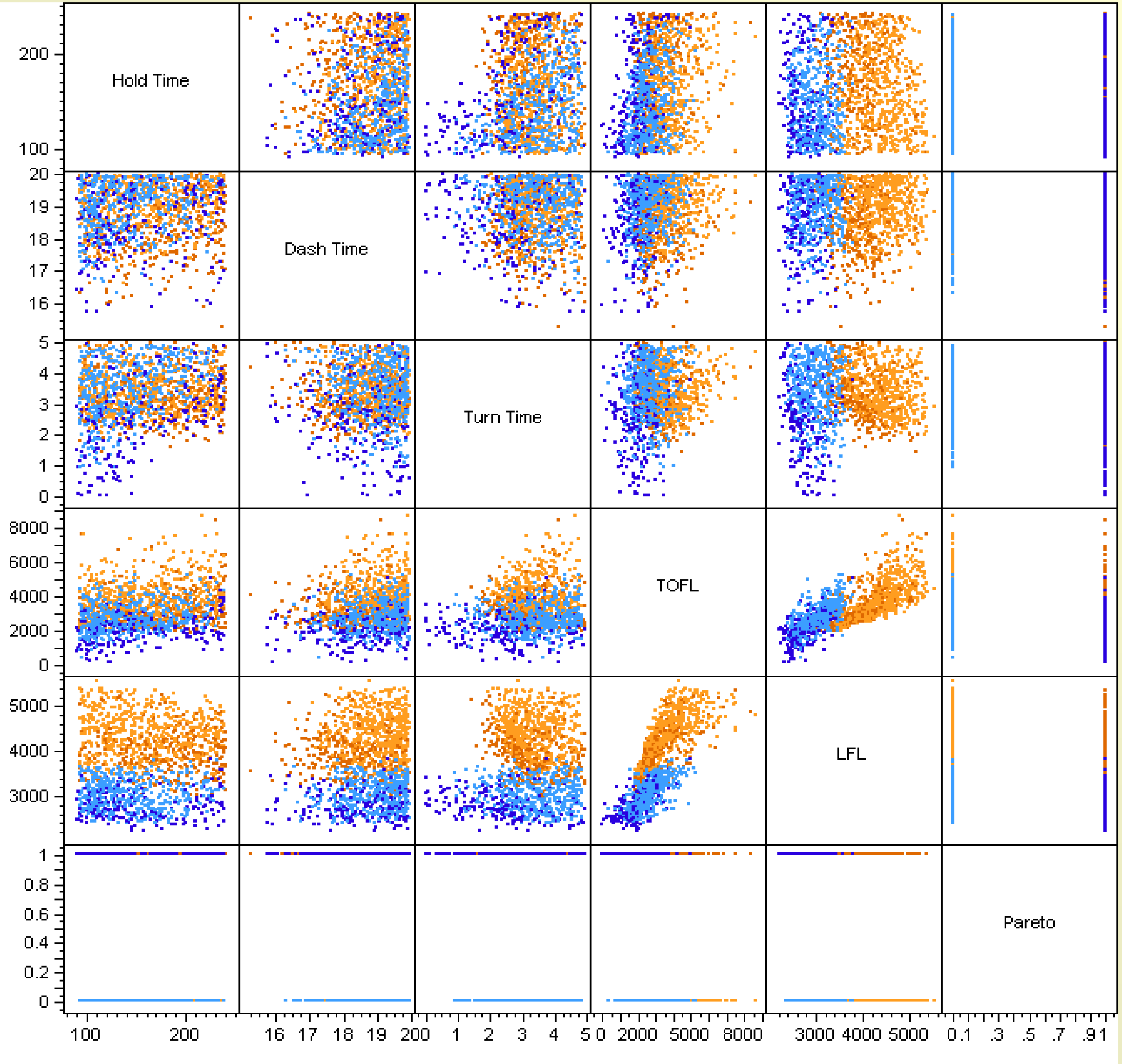


Family of Solutions – Thousands of Runs

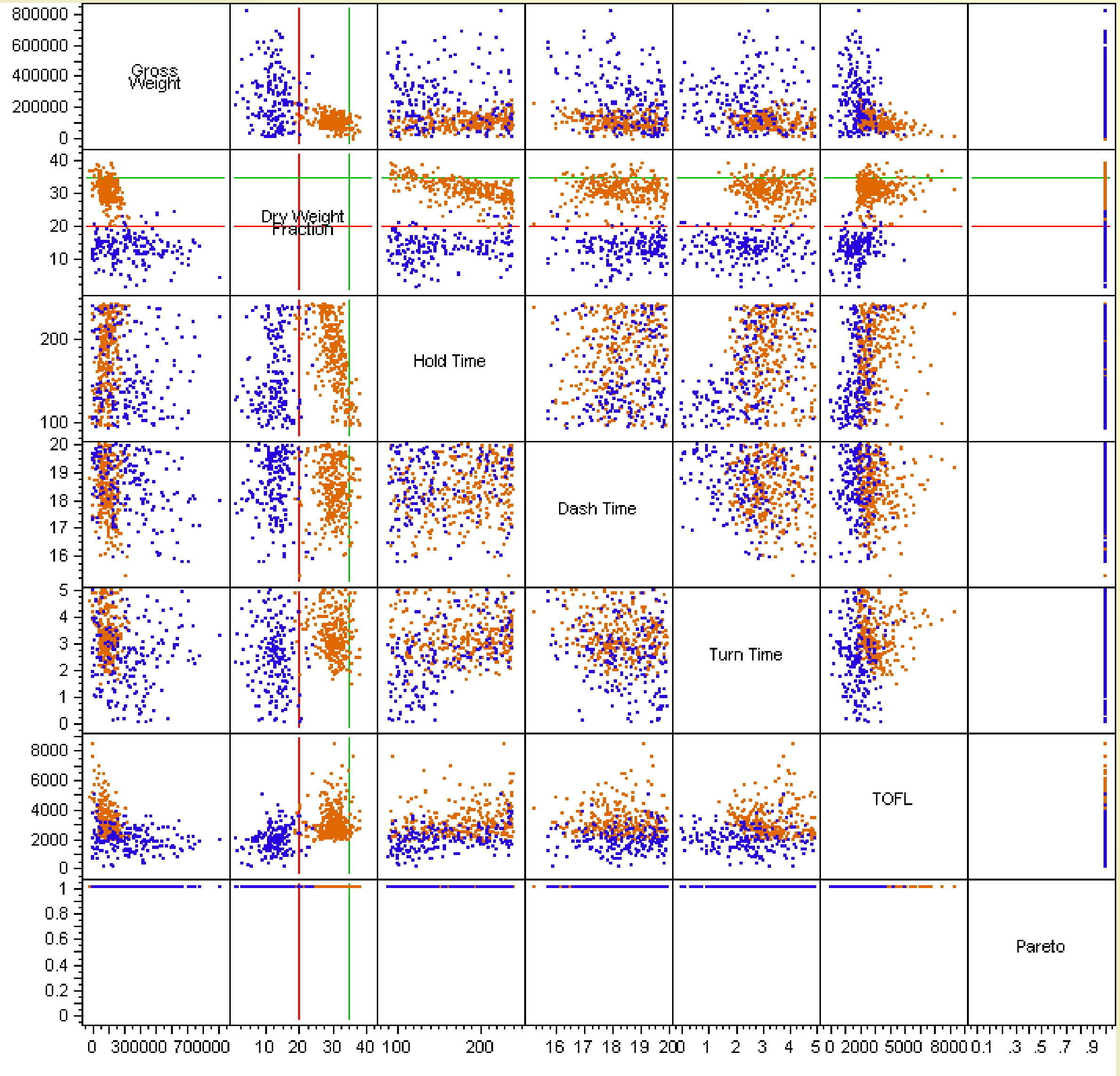
- Sample results shown – other dimensions of results also collected (e.g. gross weight)
- Removing designs above or below threshold values will show what freedom remains in other dimensions of design/solution space
- One goal of approach is to find how much design freedom a given decision (e.g. requesting dash time to be less than 20 minutes) restricts



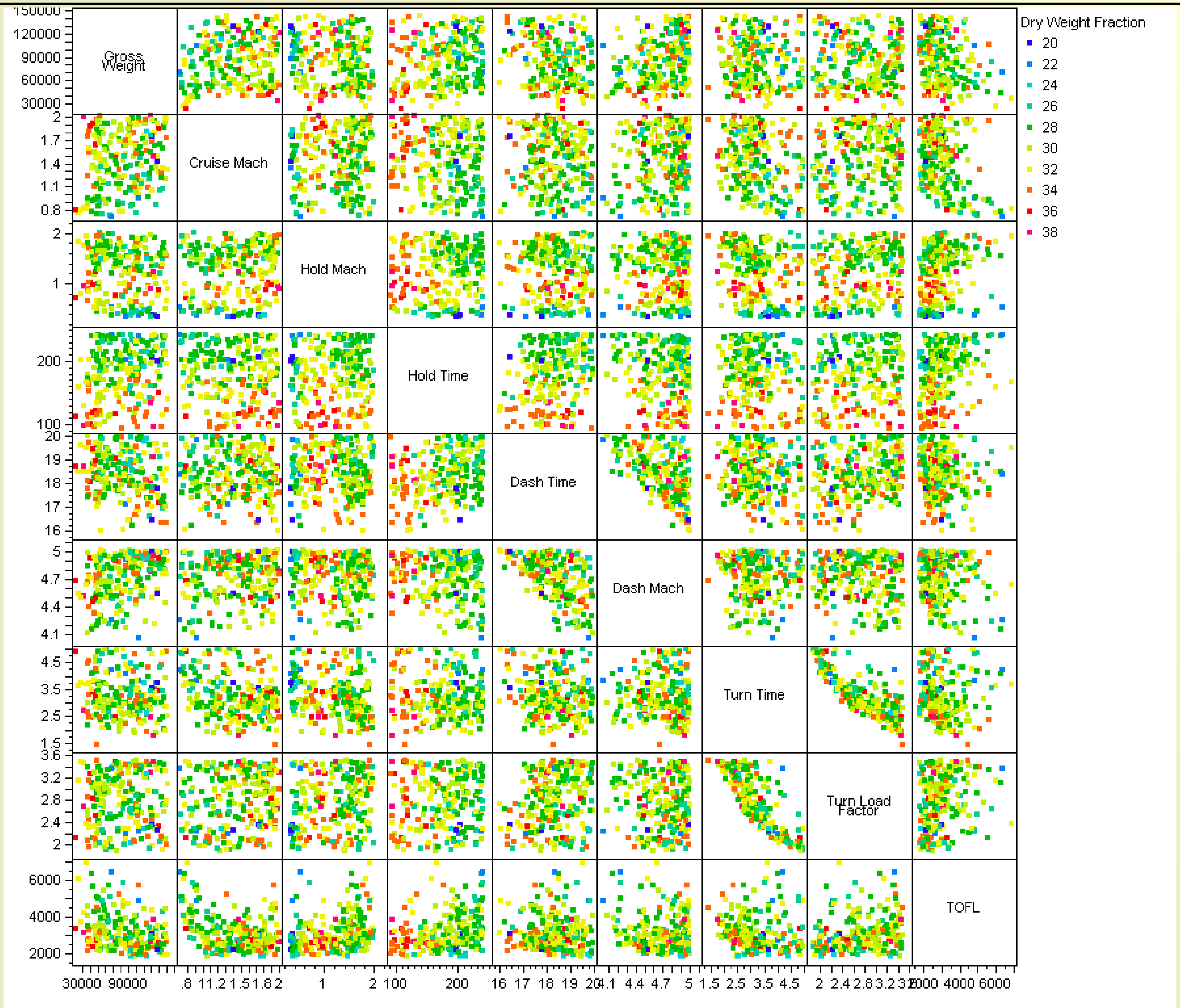
Solution Space 1 – Feasible Pareto Optima



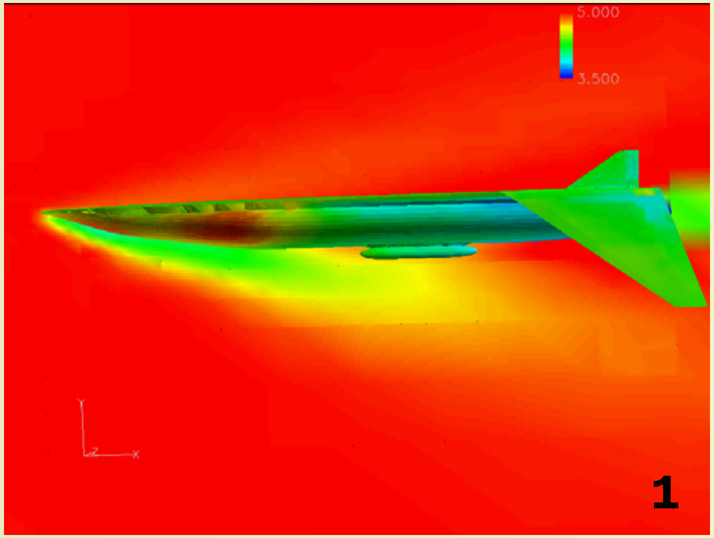
Solution Space 2 – Filtering on Dry Weight

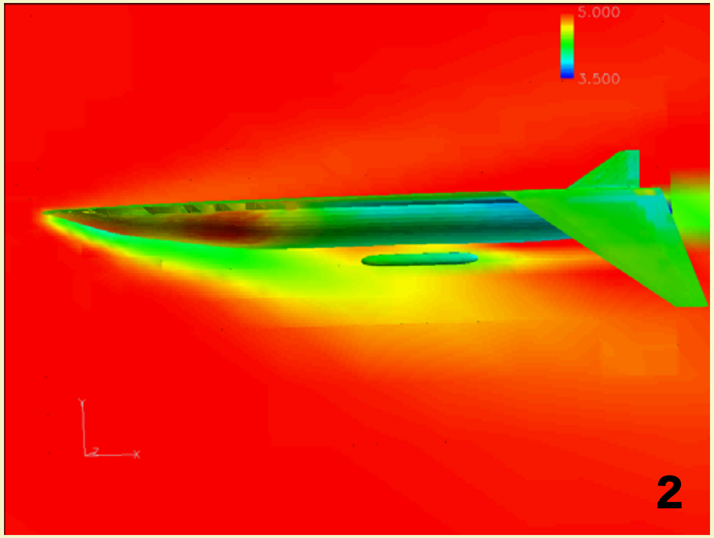


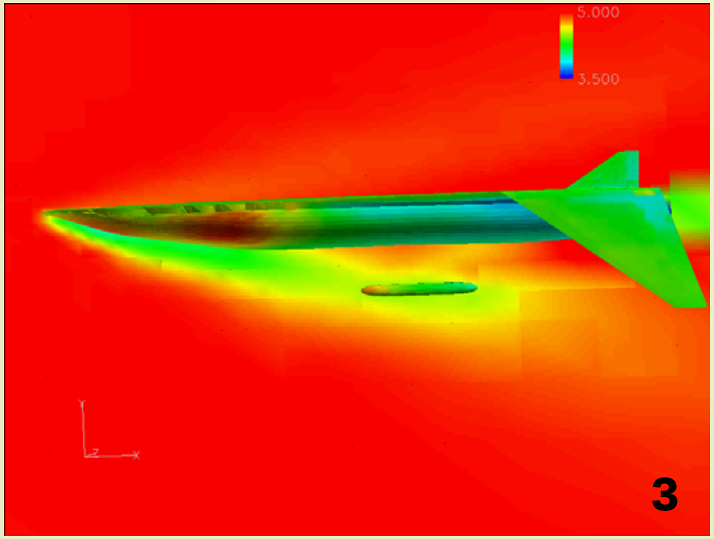
Solution Space 3 – Projection of Dry Weight into Other Dimensions

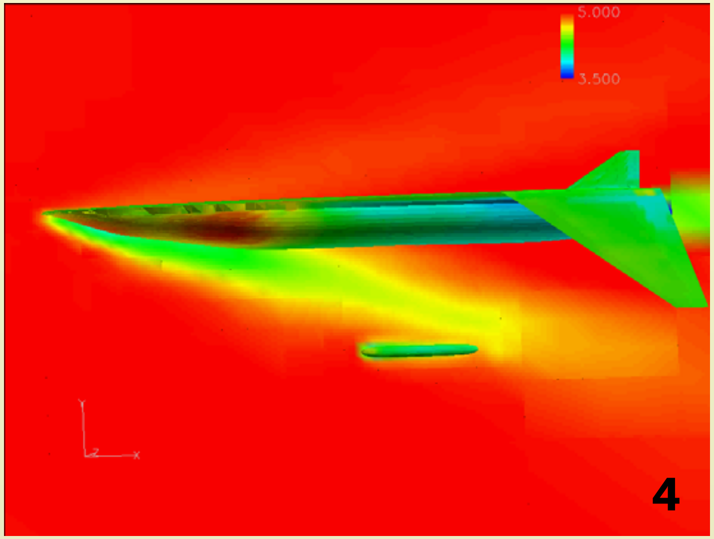


Payload Release Analysis (Mach 5)







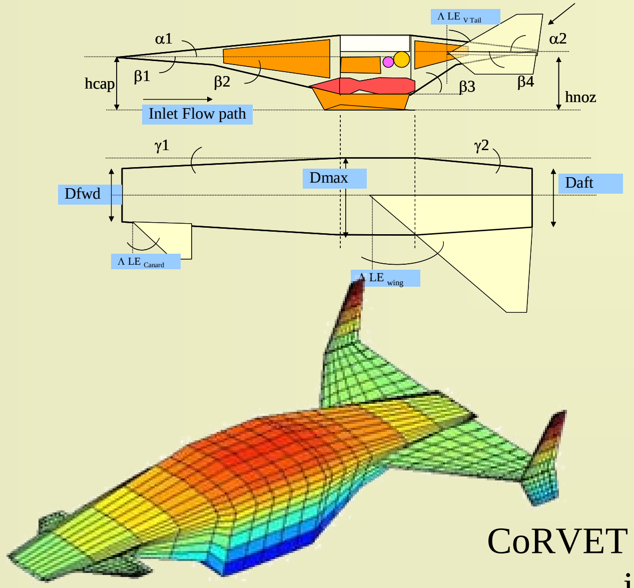


Overview

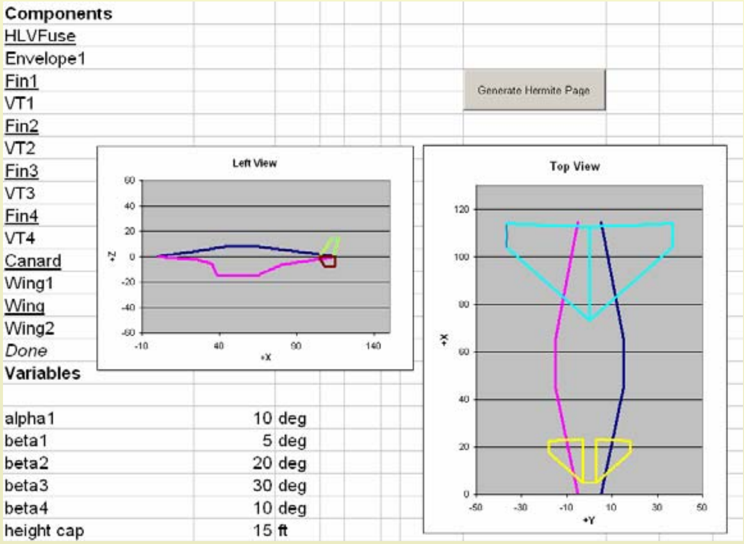
- RASAC: First-order hypersonic vehicle sizing code
- Design projects
  - Support of TBCC analysis effort
  - Design of morphing hypersonic strike vehicle
- New tools
  - High-Mach aerodynamics analysis environment
  - Interactive 3D trajectory visualization

CoRVET Geometry Modeler

- Excel/VBA tool to specify concept geometries for downstream analyses
- Excel portion useful for defining custom variables and higher level design parameters (ramp angles, wing aspect ratios, vehicle fineness ratios, etc.), as well as direct linkage to other spreadsheet analyses
- VBA portion outputs text files appropriate to aerodynamics codes of UDP and SHABP
  - Automatically derives interference shells from fuselage definition, trims wings and vertical tails to match shell
  - Adds appropriate features such as specifying both a slender body and a standard body (for viscous analysis)
  - Roughly 5,000 lines of VBA to write UDP and SHABP geometries



Concept to CoRVET


Components
HLVFuse
Envelope1
Fin1
VT1
Fin2
VT2
Fin3
VT3
Fin4
VT4
Canard
Wing1
Wing
Wing2
Done

Variables

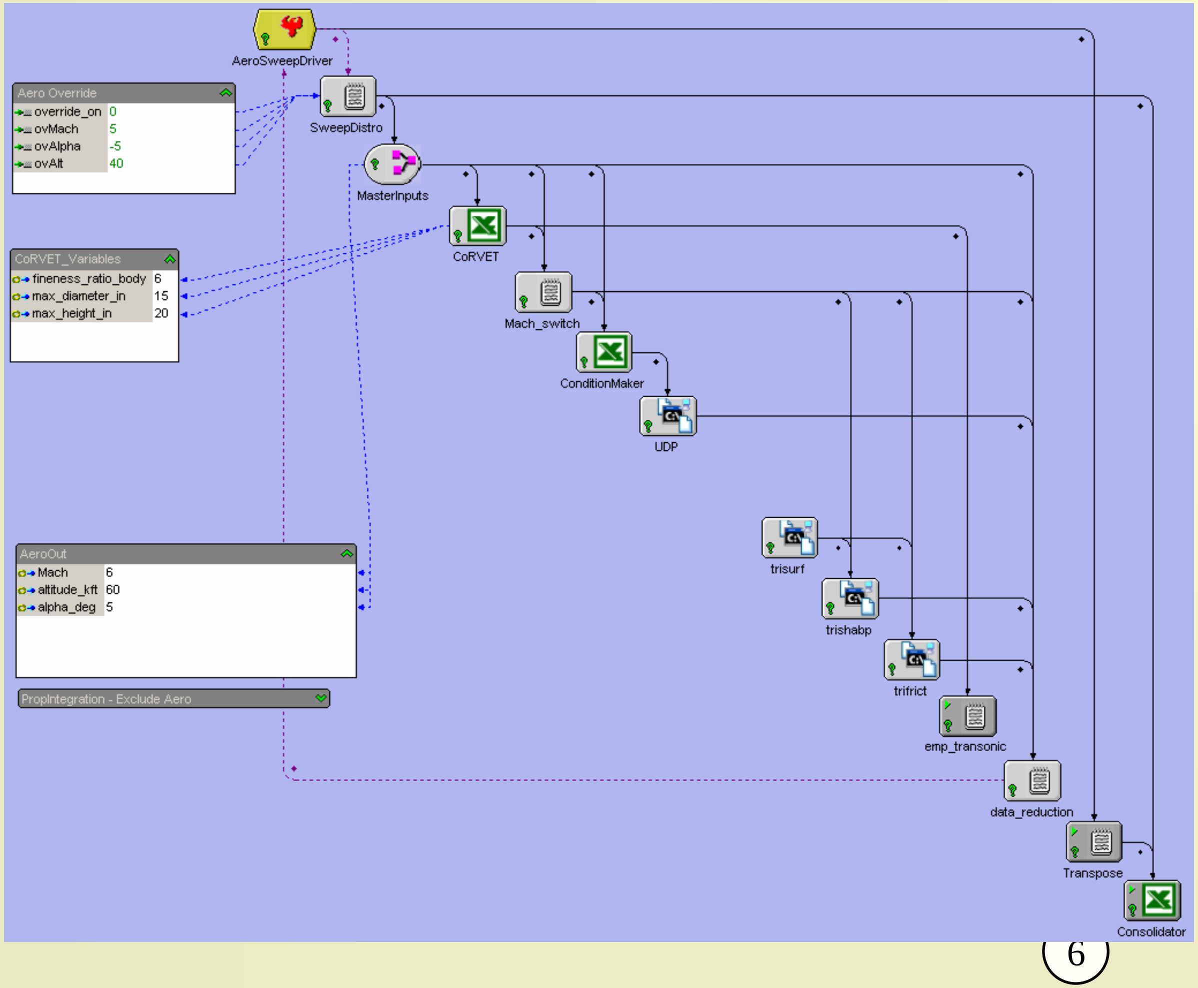
alpha1	10	deg
beta1	5	deg
beta2	20	deg
beta3	30	deg
beta4	10	deg
height cap	15	ft

CoRVET to *.hrm file, UDP input deck

MUSTANG Aerodynamics Tool

- MUSTANG incorporates freeware enhancements to SHABP developed in ASDL (triSHABP and trifrict tools), UDP from APAS-II and SHABP Mark V
- Custom interpreters developed to enable UDP execution without APAS
  - Read in plot conditions from text file
  - CoRVET generates APASIN decks from scratch
  - Interpreters parse binary *.plot files from APAS into text decks
- TriSHABP creates text file inputs for SHABP from triangulated *.hrm geometry specifications
- Results from aerodynamics tools are collected and incorporated into a single aerodynamics deck
  - Bridging functions available to smooth results from one software to another
  - Empirical transonic relationships applied to wave drag portion of UDP output to find M_{crit} and fill in between M_{crit} and $M = 1.0$
- Run time: about 15 seconds per case on average desktop PC
  - About 30 minutes to run all 96 M, h, AoA combinations

MUSTANG ModelCenter Environment



Aero Override

override_on	0
ovMach	5
ovAlpha	-5
ovAlt	40

CoRVET_Variables

fineness_ratio_body	6
max_diameter_in	15
max_height_in	20

AeroOut

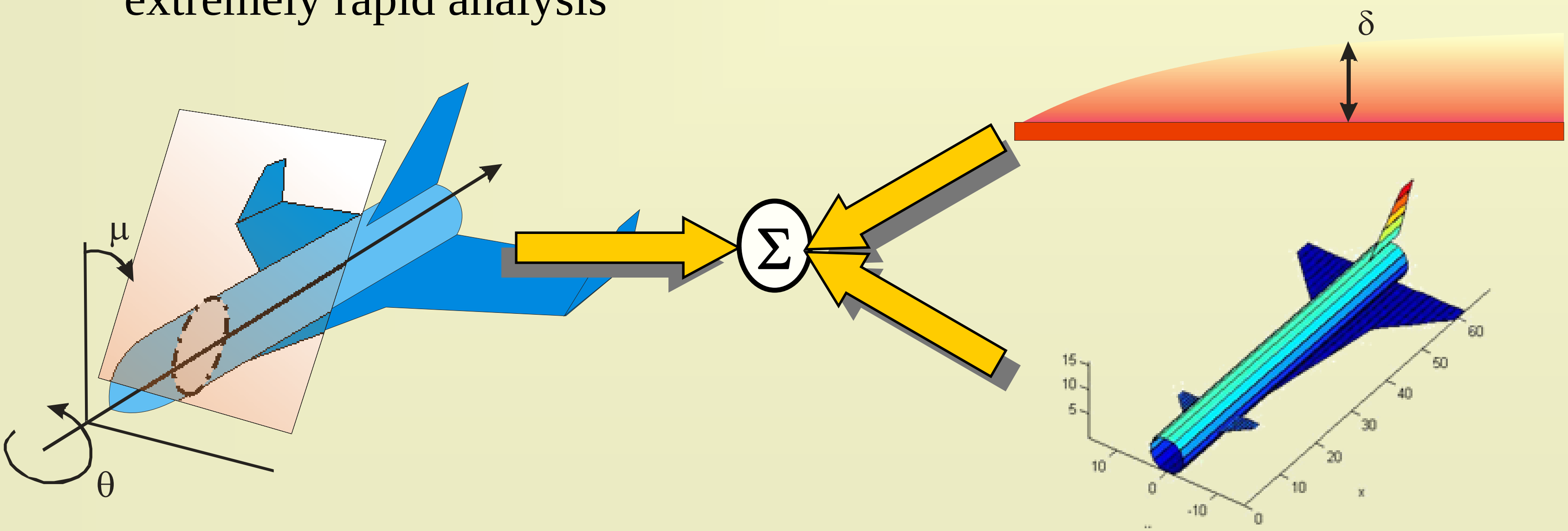
Mach	6
altitude_kft	60
alpha_deg	5

PropIntegration - Exclude Aero

- 1) CoRVET
- 2) condin writer
- 3) apasin / condin / UDP / apasdat
- 4) trisurf
- 5) triSHABP
- 6) Data parser / merger

MUSTANG: Principles of UDP

- Linear analysis code
    - Sums contributions from lift-induced vortex drag, lift-induced wave drag, volume wave drag, flat-plate viscous drag and form drag contributions
    - Vortex panel method enhanced by boundary conditions from slender body calculations to account for fuselages
- Analyses applied to components of configuration depending on their type
- Physics highly simplified for feasible compute times circa 1970 – now extremely rapid analysis

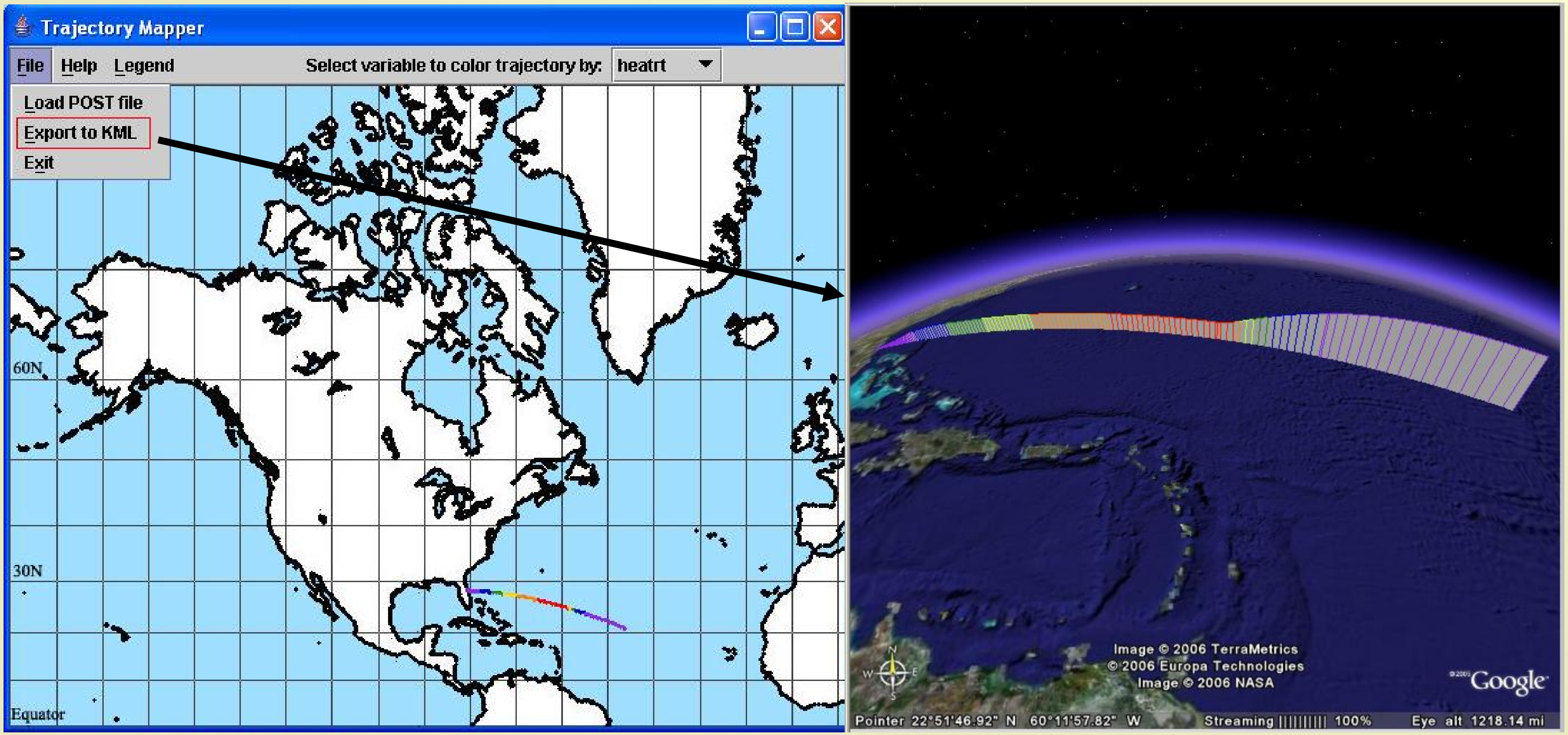


MUSTANG: Principles of SHABP

- Supersonic/hypersonic impact code
- All calculations done on the basis of a deflection angle between free-stream flow and model element normals
- Large variety of formulas available to account for various importance of flow phenomena
  - Formulas with conical/wedge flow analogues
  - Semi-empirical formulas
- Normals are all that matter
  - Originally drawn up as quads
  - Can be fed triangular elements to better represent geometries and avoid redundant elements via TRISHABP

Trajectory Mapping Tool (TRAM)

- Java tool which visualizes POST trajectories
- TRAM allows for Mercator projections colored by the values of POST output file variables
  - User can quickly browse a 2D pictorial representation for each POST output variable
- Data may be exported to a kml (Google Earth) format
  - Allows for interactive 3D trajectory renderings using Google Earth



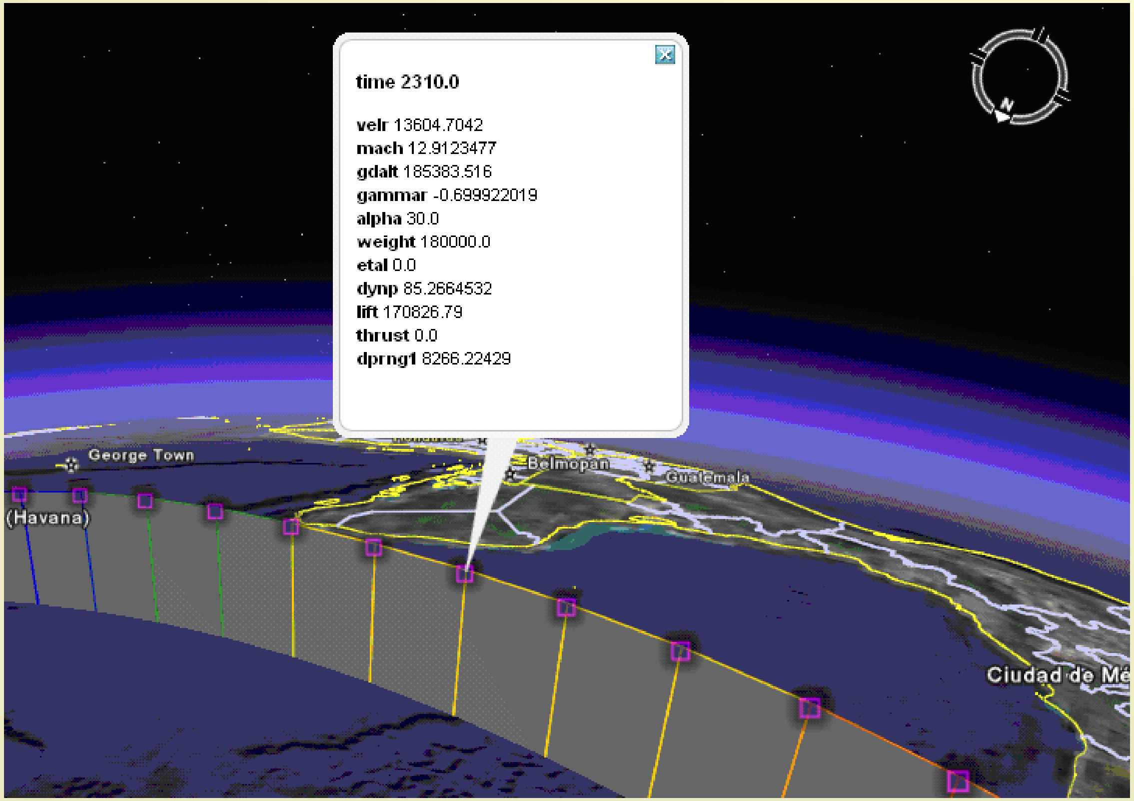
Select variable to color trajectory by: heatrt

TRAM: Leveraging Google Earth

- Opening the kml file with Google Earth will show the POST trajectory over a high-resolution and zoomable "Earth", with an intuitive, highly interactive user interface
- User selects which output variable coloration will be passed to the exported kml file
- Kml generation can be either run either manually or automatically
- The final approach for a return trajectory is shown below

TRAM: Display of Additional Variables

- Each trajectory point in the KML file contains
  - 3D coordinates that determine the position of the trajectory point in Google Earth
  - Data for a variable selected by the user during KML generation in TRAM that determines the color of the trajectory point in Google Earth
  - If available in the POST file these key variables are displayed when a trajectory point is clicked on
    - Velr, Mach, Gdalt, Gammar, alpha, Weight, Etal, Dynp, Lift, Drag, Thrust, Effisp, videal, Dprng1



time 2310.0

velr 13604.7042
mach 12.9123477
gdalt 185383.516
gammar -0.699922019
alpha 30.0
weight 180000.0
etal 0.0
dynp 85.2664532
lift 170826.79
thrust 0.0
dprng1 8266.22429