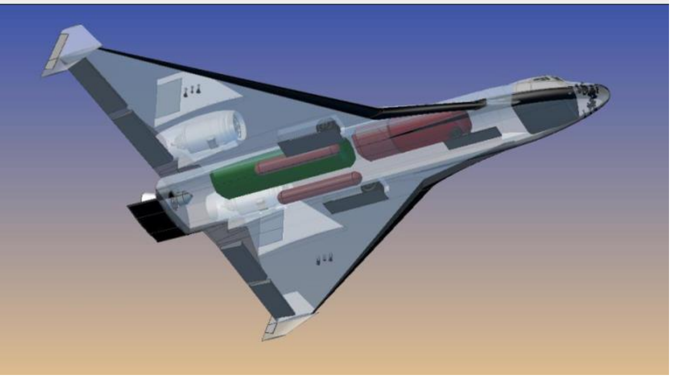
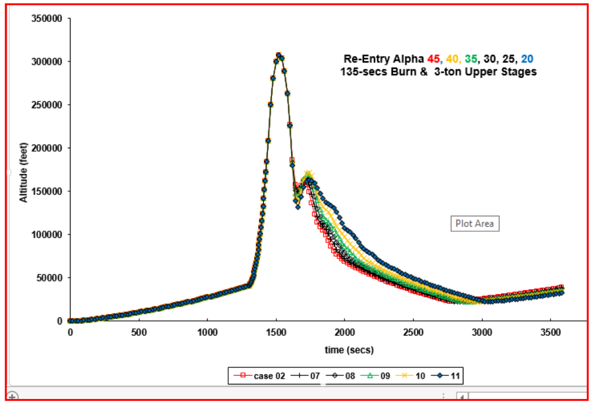
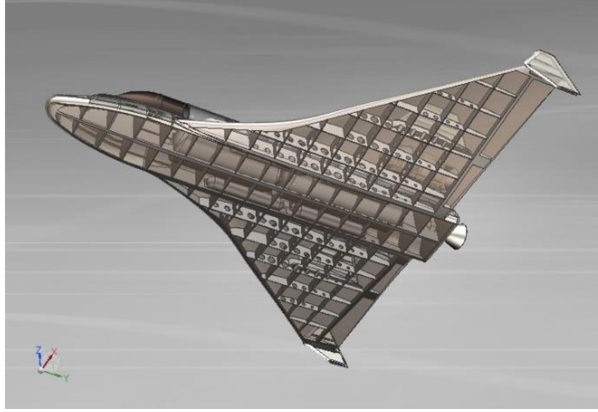






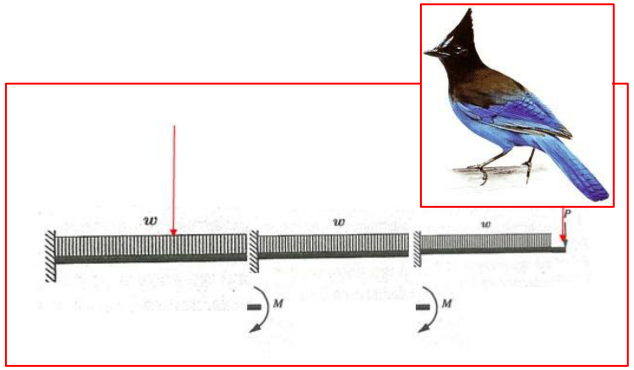
$$S_w = \int_0^{\frac{b}{2}} x_2(y)\,dy - \int_0^{\frac{b}{2}} x_1(y)\,dy$$

$$S_w = \int_0^{\frac{b}{2}} [C_R) + \tan(\Lambda_{le})y]\,dy - \int_0^{\frac{b}{2}} \tan(\Lambda_{te})\,y\,dy$$

$$= C_R\ (b/2) + \tan(\Lambda_{le})\ /2\ (b/2)^2 - \tan(\Lambda_{te})/2\ (b/2)^2$$

A Partially Re-Usable Horizontal Take-off & Landing Launch Vehicle

A Continuing Case Study



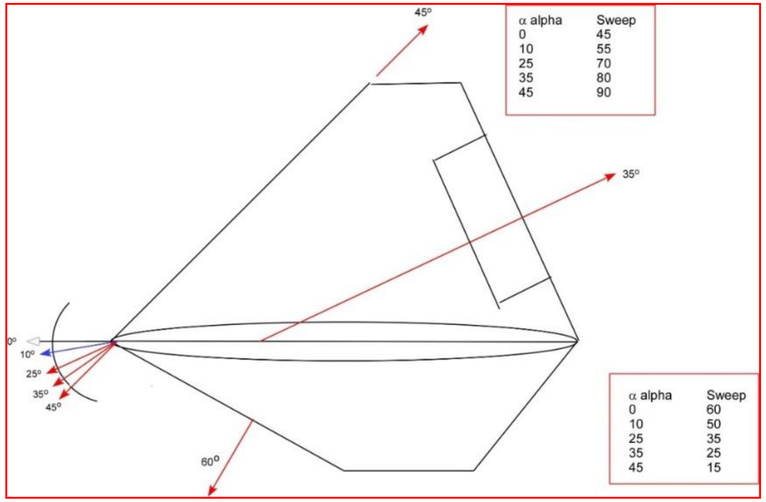
Wes Kelly

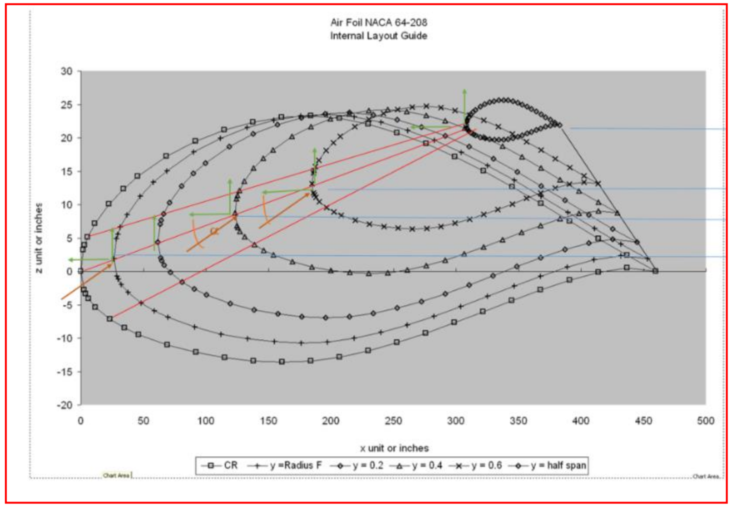
Triton Systems, LLC
17000 El Camino Real – Suite 210A
Houston, TX 77058

University of Houston Clear Lake

Houston, TX

12 February 2018





Abstract

Historically, reusable and expendable launch systems have experienced rising and falling tides,
but also variations in approach.

Among reusable concepts, 1st stages combining aircraft and rocket features have been examined less often.

This case includes horizontal take-off and landing (HTOL) craft with wings and air breathing engines; transitioning to rocket propulsion occurs at subsonic speed (M<1) and stratospheric altitude.

Stage recovery comes after separation of an expendable upper stage at rocket shutdown and subsequent coast to apogee and descent – heading off ultimately to a runway.

The locally based Stellar J project examines this approach, addressing integration, performance, preliminary design, missions and markets.

Scalability of the concept is examined based on constraints of hardware and markets.

Several applications prove promising, the most immediate: deployment of small satellite constellations.

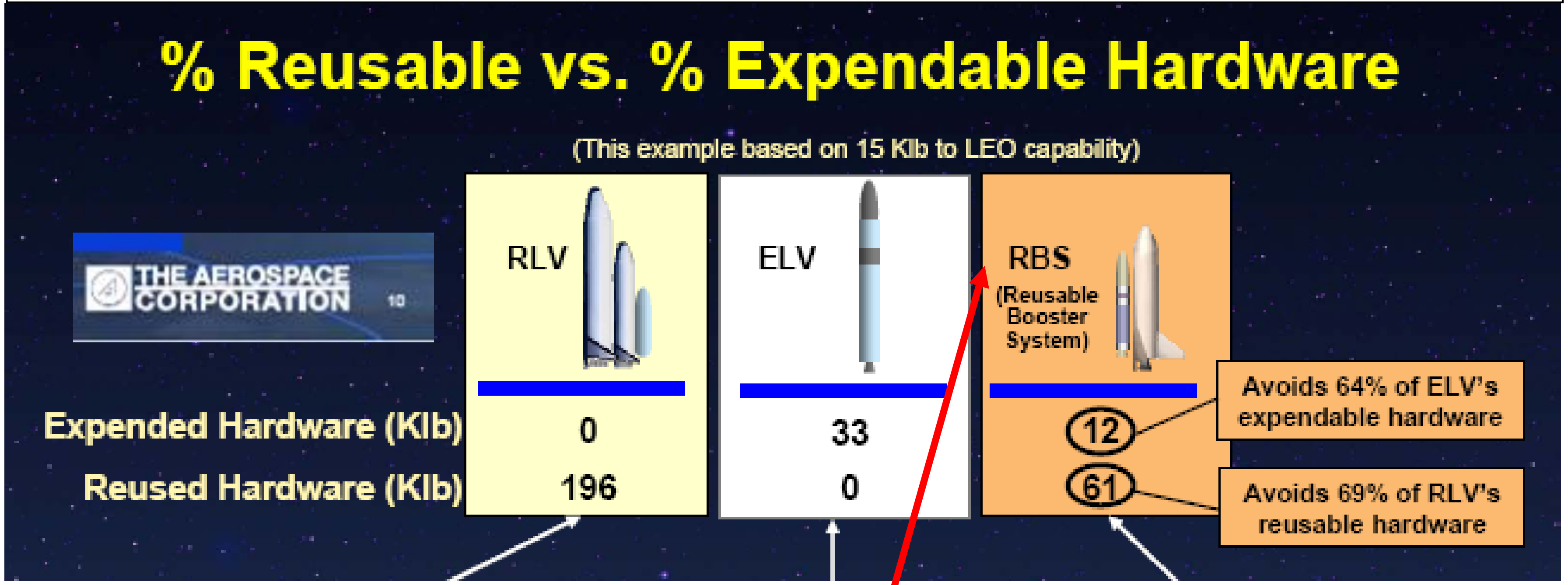
As design has matured, aero-thermal and structural studies have become more and more focused and hardware trades address the specifics of a design distinct in nature.

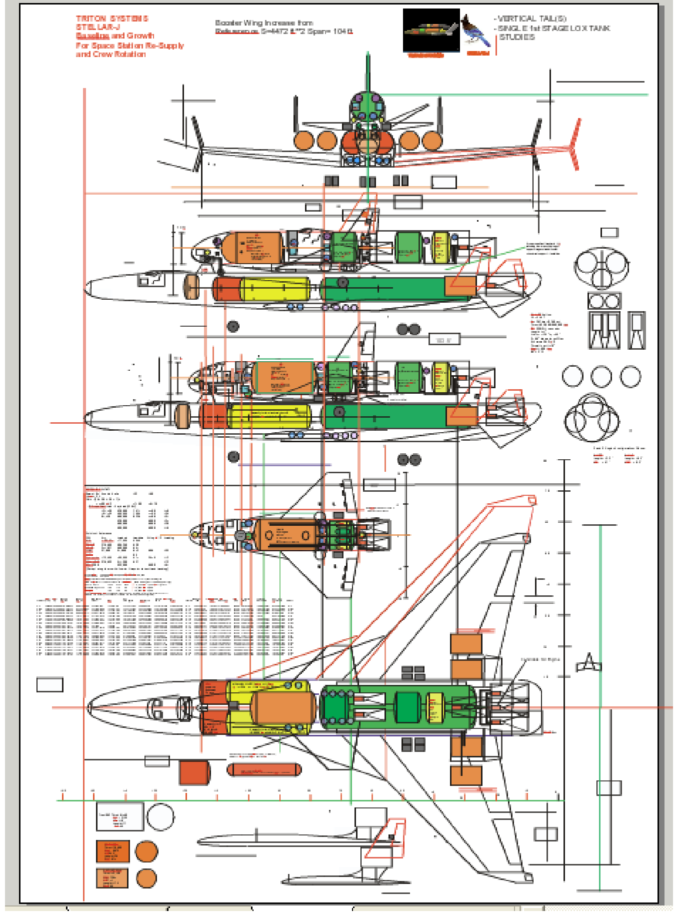
At American Institute of Aeronautics & Astronatics “Space 2007” convention in Long Beach, CA
Then Aerospace Corporation CEO & President Dr. William Ballhaus gave the keynote address.

Reviewing launch system development since Sputnik & the direction
US should take for the next 50 years, Ballhaus recommended:

A partially reusable launch vehicle, concentrating reusability in the 1st stage;
A vehicle with wings, air-breathing jets as well as rocket engines;
Flying frequently, responding rapidly and able to deploy different upper stages (expendable or reusable) allowing for flexible operations.

Unknown to Dr. Ballhaus
Triton Systems, LLC was working
to develop such a vehicle …
The Stellar-J >>





RBS has potential for more cost-effectiveness

But there was still one key difference…

Current (2008) programmatic references to “hybrid launch” vehicles & reusable first stages assume vertical launch and horizontal landing. Historically this was not always the case.

22nd Annual Small Conference on Small Satellites

(August 2008 – Logan, Utah)

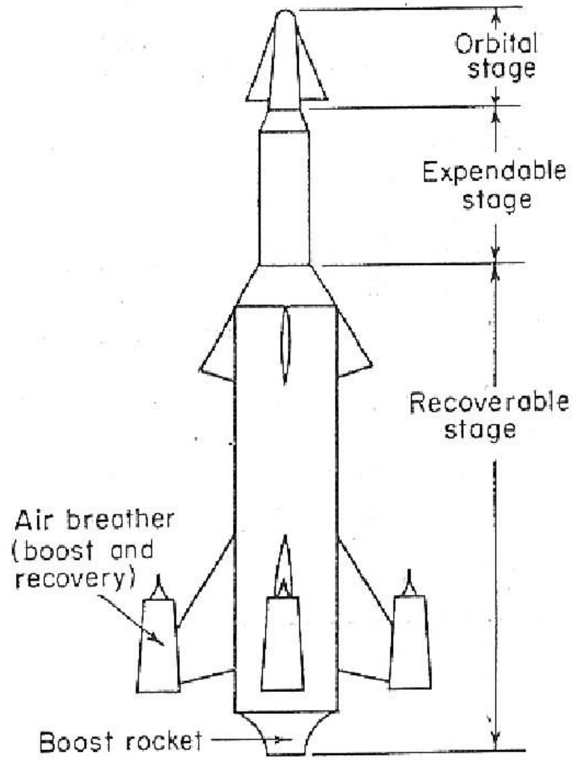


FIG. 18.15 Vertically launched booster.

18.33 Boost-vehicle Configuration

Air-breathing boost vehicles can be designed either for vertical launch and recovery or for

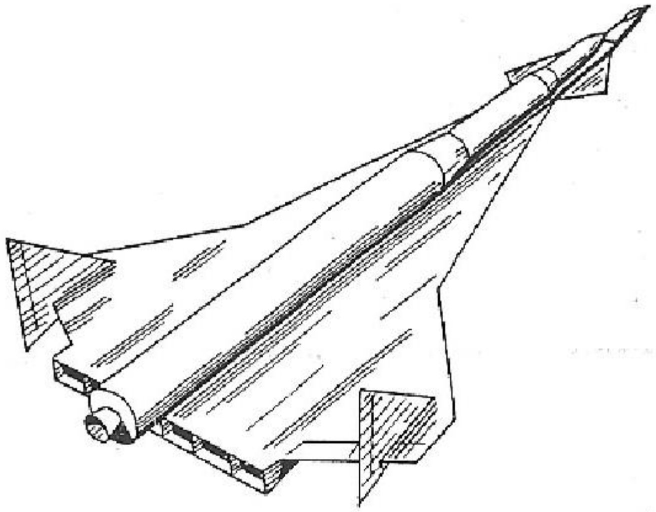


FIG. 18.16 Horizontally launched air-breathing boost vehicle.

From “Air-Jet Propulsion Systems” by P. G. Kappus, In *The Handbook of Astronautical Engineering*, Heinz H. Koelle, editor, New York, 1961.

Though VTO vs. HTO design controversies multi-faceted issues, we noted most participants to Small Satellite Conference arrived in Logan via

HTO craft

due to

- **proven operating capabilities,**
- **frequent launch opportunities,**
- **convenient infrastructure…**

Compared to the VTO Alternative.

The Planning for Partially Re-Usable Launch Vehicles Was Based on Vertical Take Off

Shuttle derivative & upgrade studies of the 80s & 90s Included Liquid Rocket Boosters to replace existing Solid Rocket Boosters.

Beside expendable LRBs In late 1990s, work included Liquid Fly-Back Boosters with wings and reusable rocket engines, cruising back to launch site in final sub-sonic flight leg on jet engine power.

Booster power plants featured newly available long-life, high performance kerosene-LOX staged combustion engines. RD-180 and several alternates. were rated for numerous starts.

Liquid Fly-Back Booster concepts, systems and hardware Re-arranged and re-scaled result in the HTO reusable first stage (RFS) described.

But the launch system need not weigh 2000 tons at liftoff.

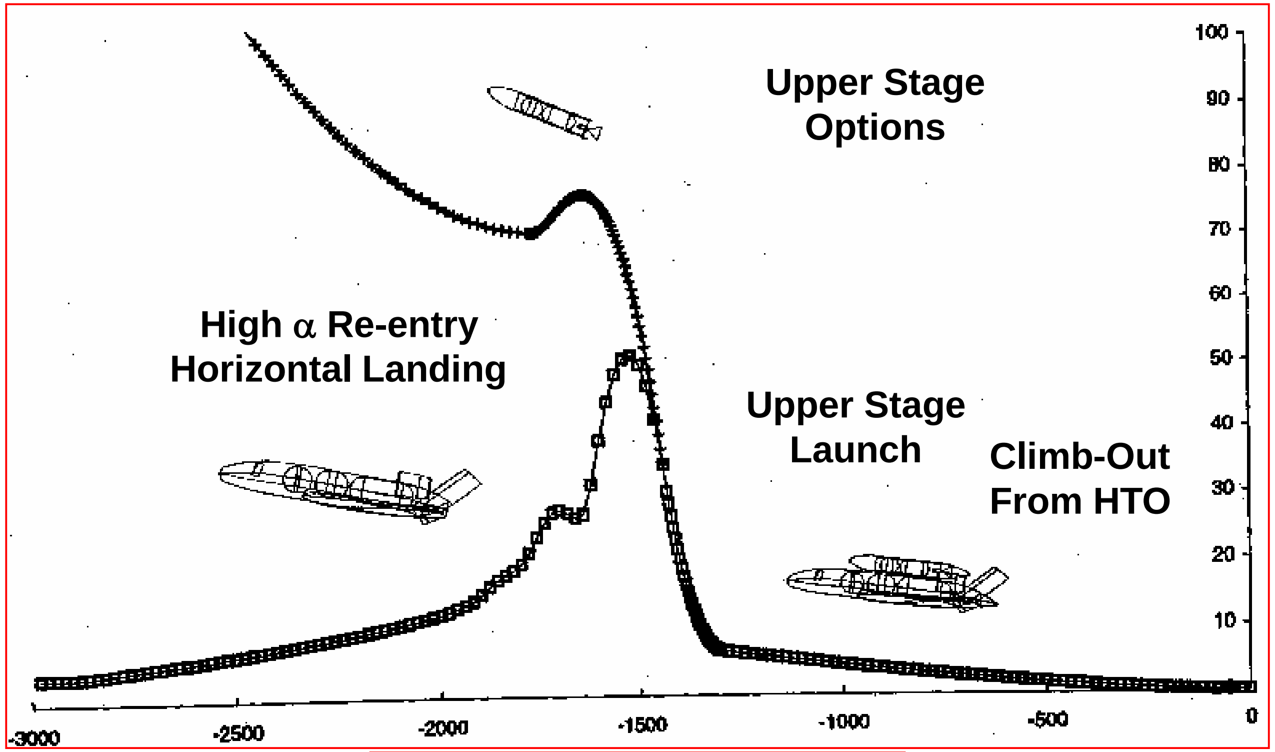
Long Standing REPRESENTATION

The Stellar-J employs horizontal take-off and landing from conventional airfields

Rocket transitions occurs at subsonic stratospheric cruise.

Vehicle climbs to rocket shutdown
at ~150,000 feet
& hypersonic velocity.
Releasing upper stages carrying payloads to orbit,

The reusable first stage returns to land & refurbishment.



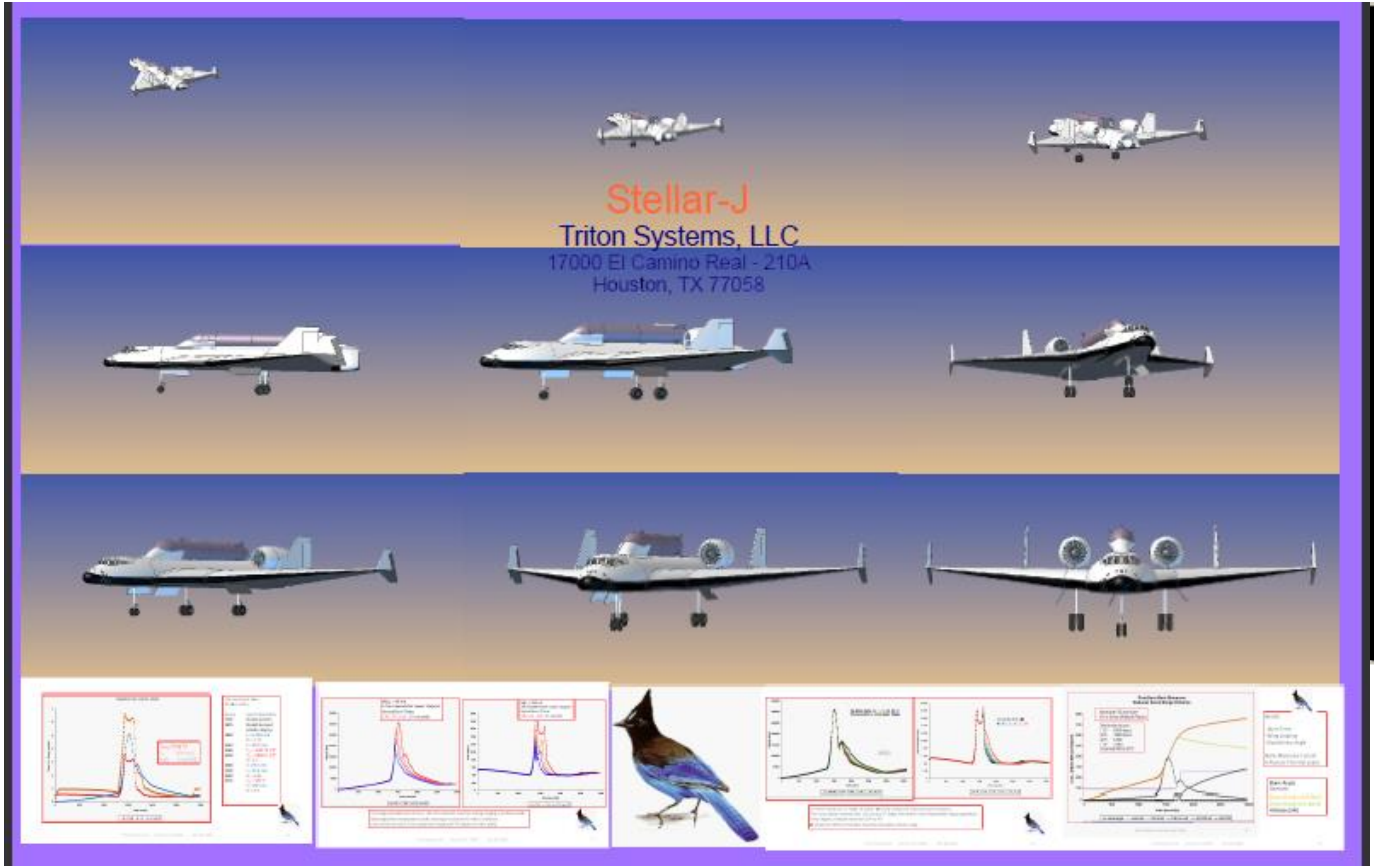
Altitude (n. mi.)

Time after takeoff (seconds)

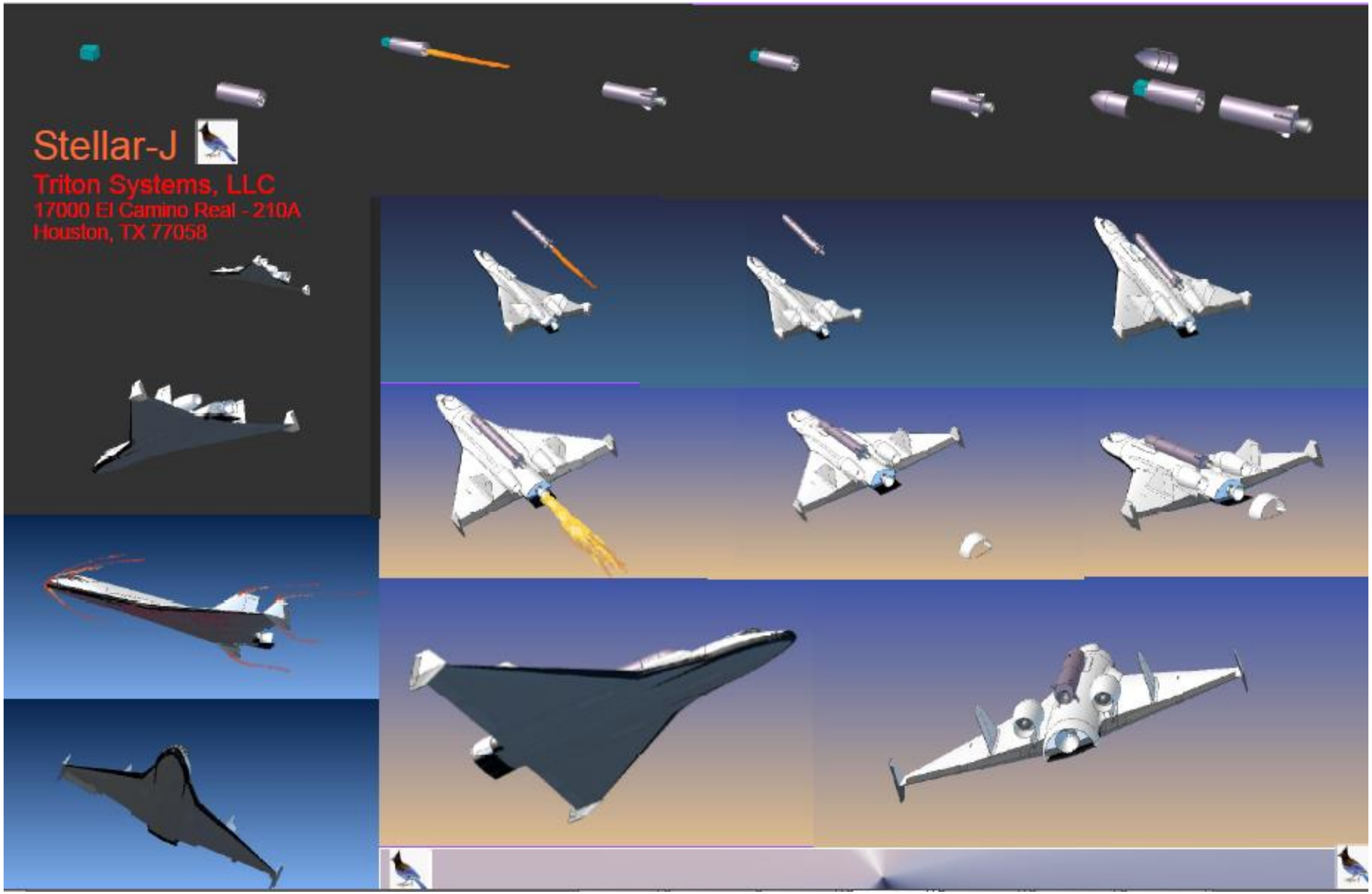
The concept scales for configurations from 35-350 tons take-off weight based on Available high performance reusable engines.

Market research shows the opportunity for the smallest initial investment & earliest returns: the small satellite market, payloads ~ 100-lbs to low earth orbit (LEO).

A standing backlog of ~500 small payloads has remained for decades awaiting launch opportunities with limited slots and market costs of $20,000 per payload pound.

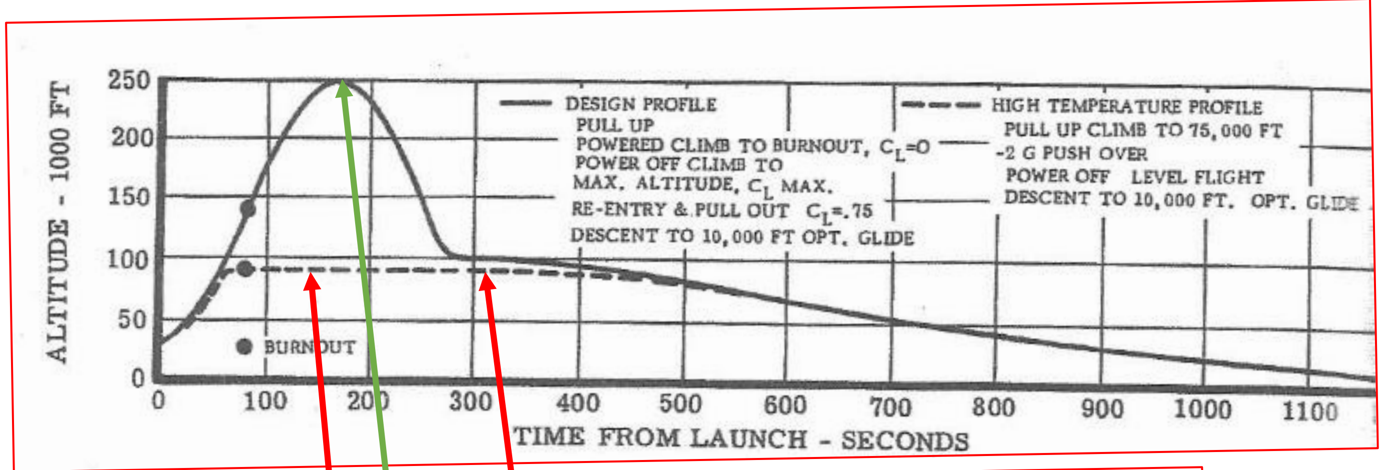


www.aiaahouston.org/newsletter/
September 2005
Cover Story, Page 5

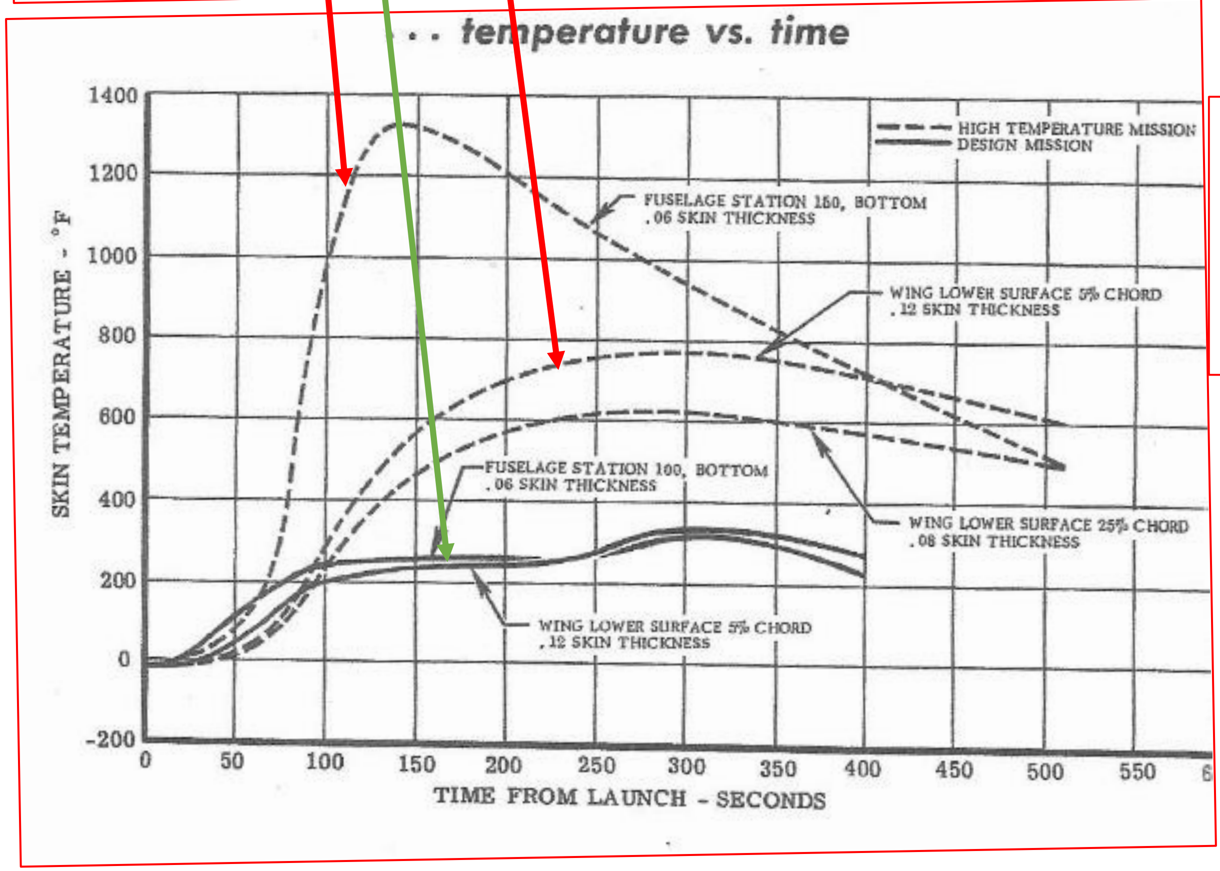


But is this Launch System a Unicorn?

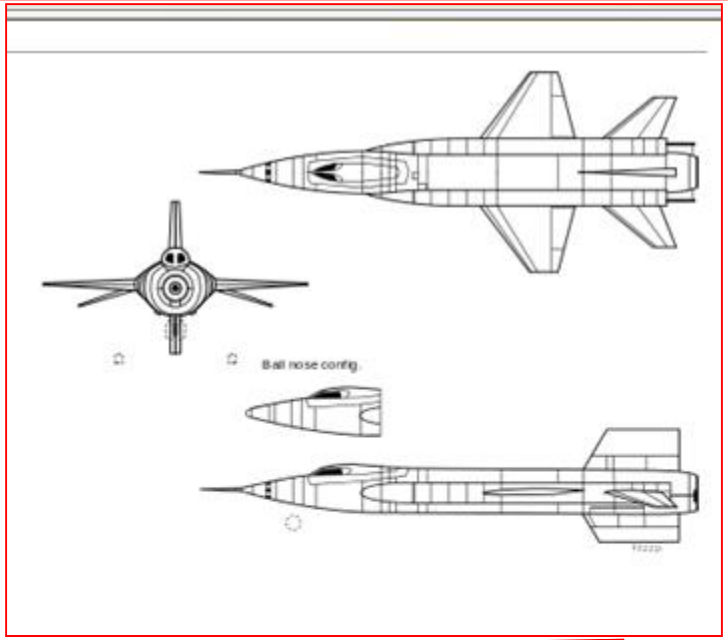
Or… Is There Something There?



All Metal Construction
Titanium & Inconel (Nickel) Alloy

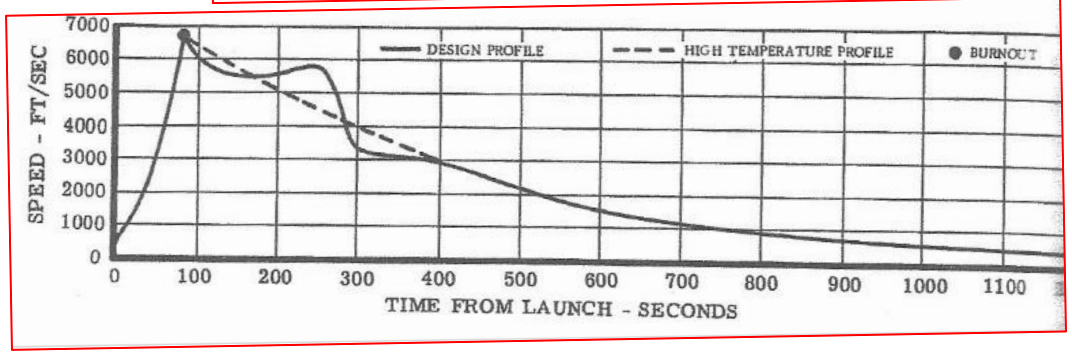


X-15
Profiles
High &
Low



Launched from a Plane
3 Aircraft
~200 flights

DESIGN MISSIONS
. . . altitude and speed vs. time



X- 34 Nominal Flight Profile

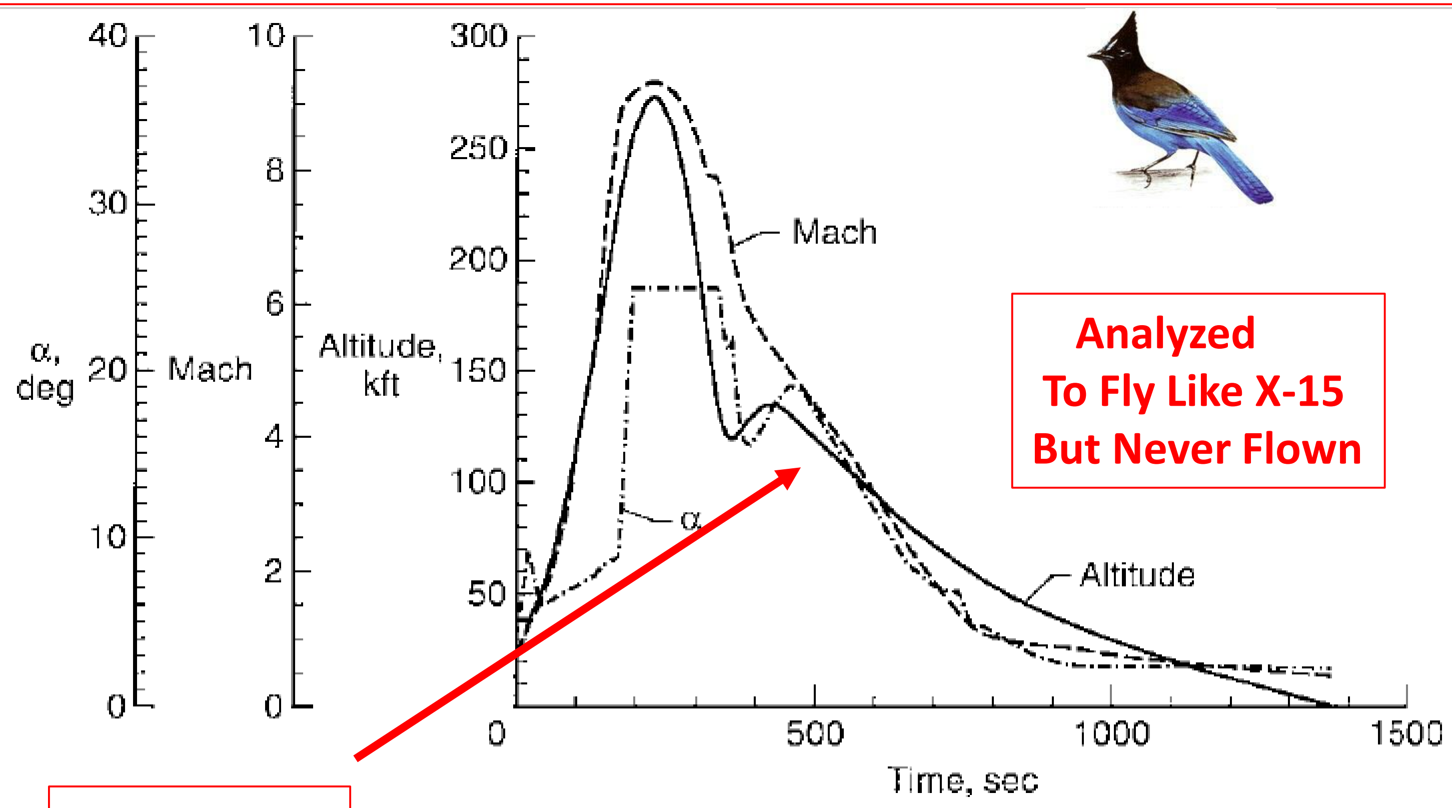


Fig. 4 WAG18D trajectory profile.

Composite Materials & TPS

Fig. 1 Artist's concept of the X-34 configuration in flight.

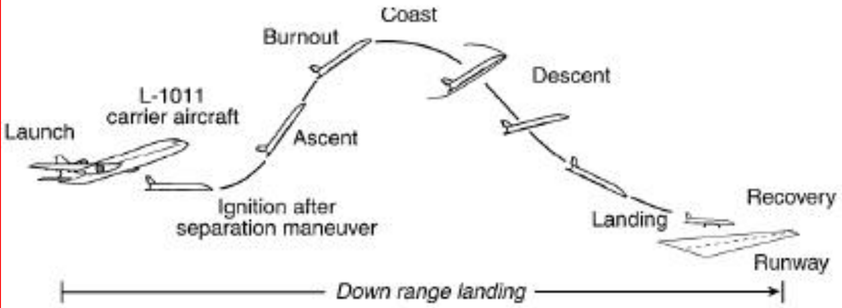


Fig. 2 Typical X-34 flight profile.

Shuttle Endeavour over Houston en route
To Retirement 2012

Voici le modèle OK-GLI de la navette spatiale soviétique Bourane, exposée maintenant au musée technique Speyer situé en Allemagne.

Space Shuttle & Buran
Ultimately Launched from Pads
Re-Entry at velocities 4 times >X-15

An HTOL with wings and air-breathing jet engines to return and re-fly the first stage makes sense if…

- The rocket engines are high performance, compact, reusable and economical
  (cheaper to reuse than to replace, a lifetime of 20 to 30 re-starts

Dependent on: $m_F/m_I = \exp(-\Delta V/(g\, I_{SP}))$ for each rocket stage

m_F: final mass before rocket burn m_I : initial mass prior to rocket burn

ΔV: velocity change due to rocket burn (measured in empty space w/o drag)

I_{SP}: Specific Impulse [(lbf thrust/ lb propellant/sec) units: seconds]

- The jet engines and wings pay their own way in combination with the performance of the rocket engines by reducing the burden of the rocket engines in flight to orbit - and assisting in re-entry.
-
- The RDT&E (non-recurring) cost and the operating (recurring) costs are competitive.

- There are existing missions, markets and customers for such services.

- The vehicle is comparatively flexible or versatile enough to go after them.

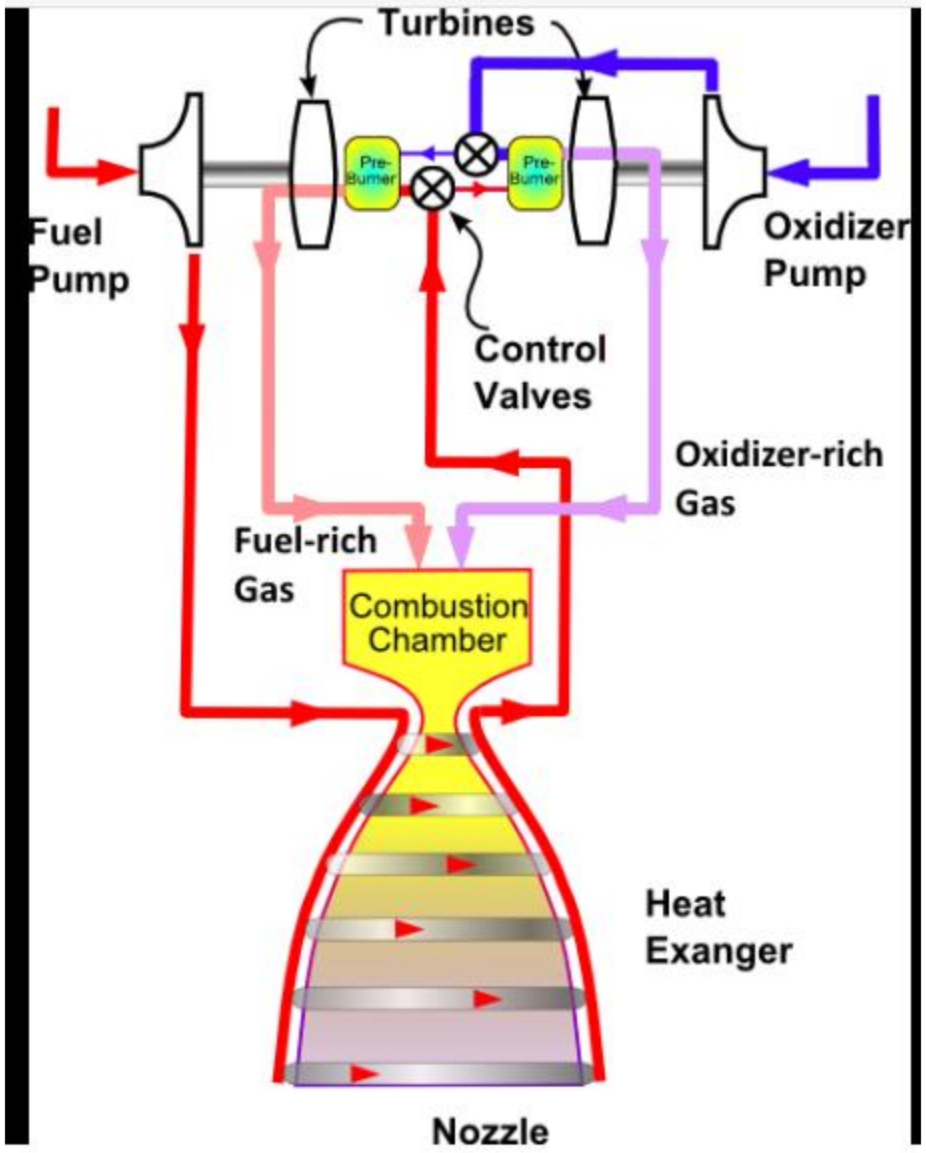
Revolutionary Products Made Available in the US in the 1990s

Valentin Petrovich Glushko
Валенти́н Петро́вич Глушко́
1909-1989
Chief Designer RD-170
LOX Rich-Kerosene
Staged Combustion Cycle
Rocket Engine
Chamber Pressure: 250 bar
(Successor: Boris Gubanov)

Beside
High Performance I_{SP}
High Thrust to Weight

Engines Long-Lived

Nikolai Dmitriyevich Kuznetsov
Николай Дмитриевич Кузнецов 1911-1995
Chief Designer of NK-31, NK-33 LOX Rich Kerosene
Staged Combustion Cycle Rocket Engine
Chamber Pressure(s): ~90 & ~150 bar
Vacuum Thrust ~ 90,000-lbf



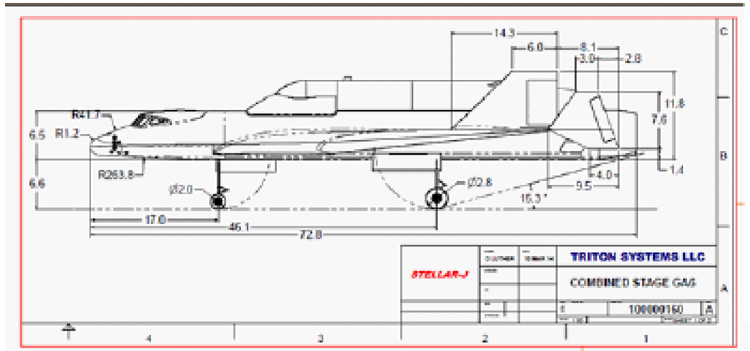
PUMP FED STAGED COMBUSTION CYCLE
(SEVERAL VARIATIONS)

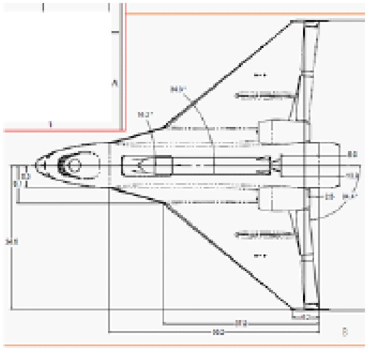
Fuel-Cooled Nozzle
Pre-Burners turn Turbines
With “Unbalanced” Exhausts
Run Propellant Pumps
High Pressure Propellant Gas Mixes
Headed to Combustion Chamber

If turbine exhausts were
To be dumped overboard
in separate exhaust,
Combustion chamber
Pressures ½ to 1/3 less.

Engine volumes increase
Thrust to weight goes down
Low altitude specific impulse decreases
Due to exit pressure in expanded nozzle.

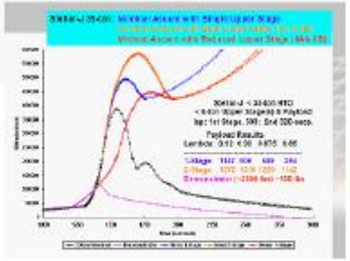
What is our answer?...

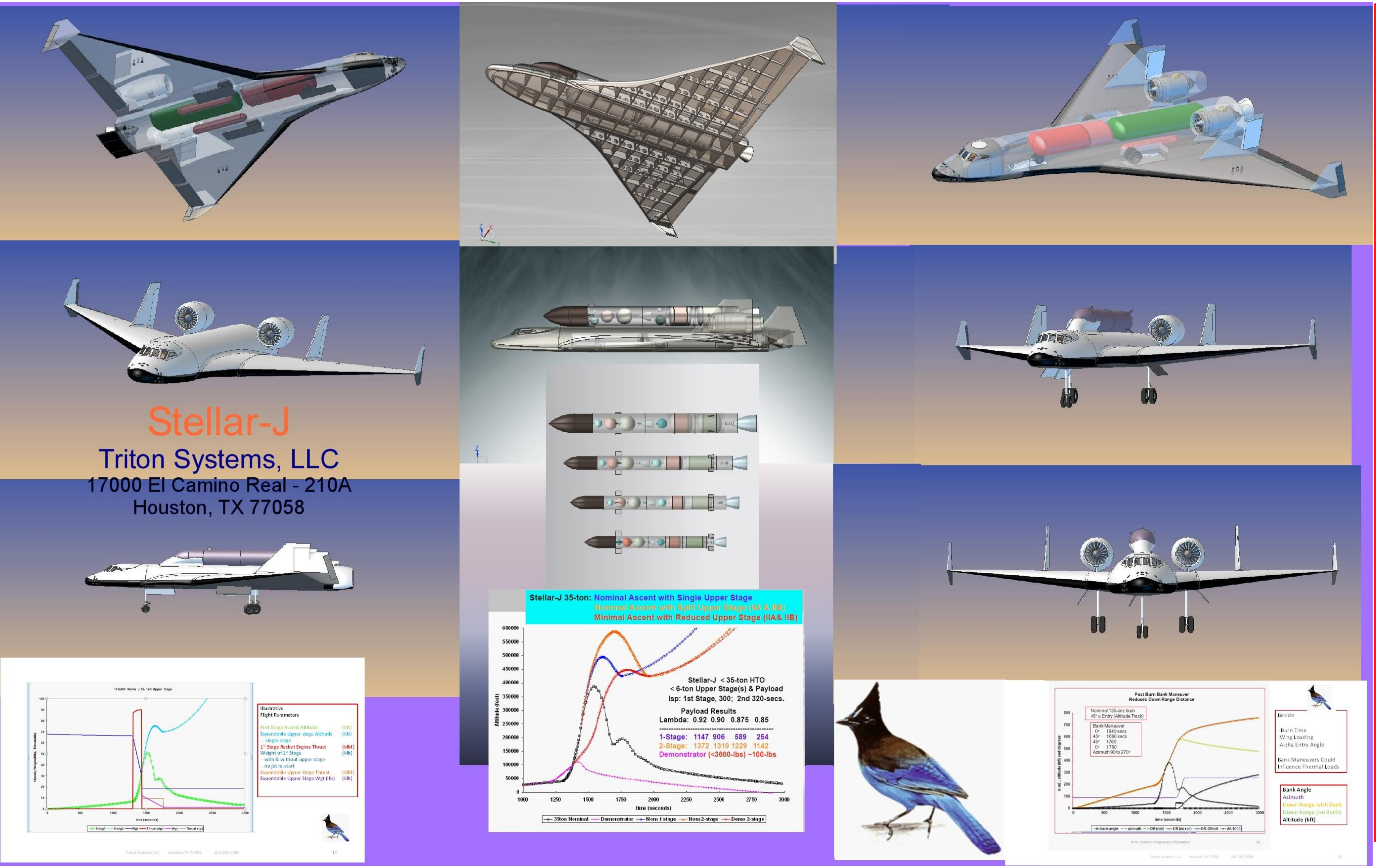




We are moving toward an HTOL:
(horizontal take-off and landing vehicle
We see it as more versatile than VTOLs
With several physical advantages.

Ellington Field or
Any Other Spaceport





Versatility

Stellar-J can select

- Ascent flight azimuth like an airplane with zig-zags or switchbacks.

- Upper stages based on mission requirements or development phase.

- Landing at launch site or down range fields.

Ferry itself to launch sites.

Flight tests without rocket ignition.

It is our objective in sharing our experience in developing such a vehicle (The Stellar-J) to relate

- Why do this? Does such a vehicle fulfill any need? Are there any advantages? Based on what?

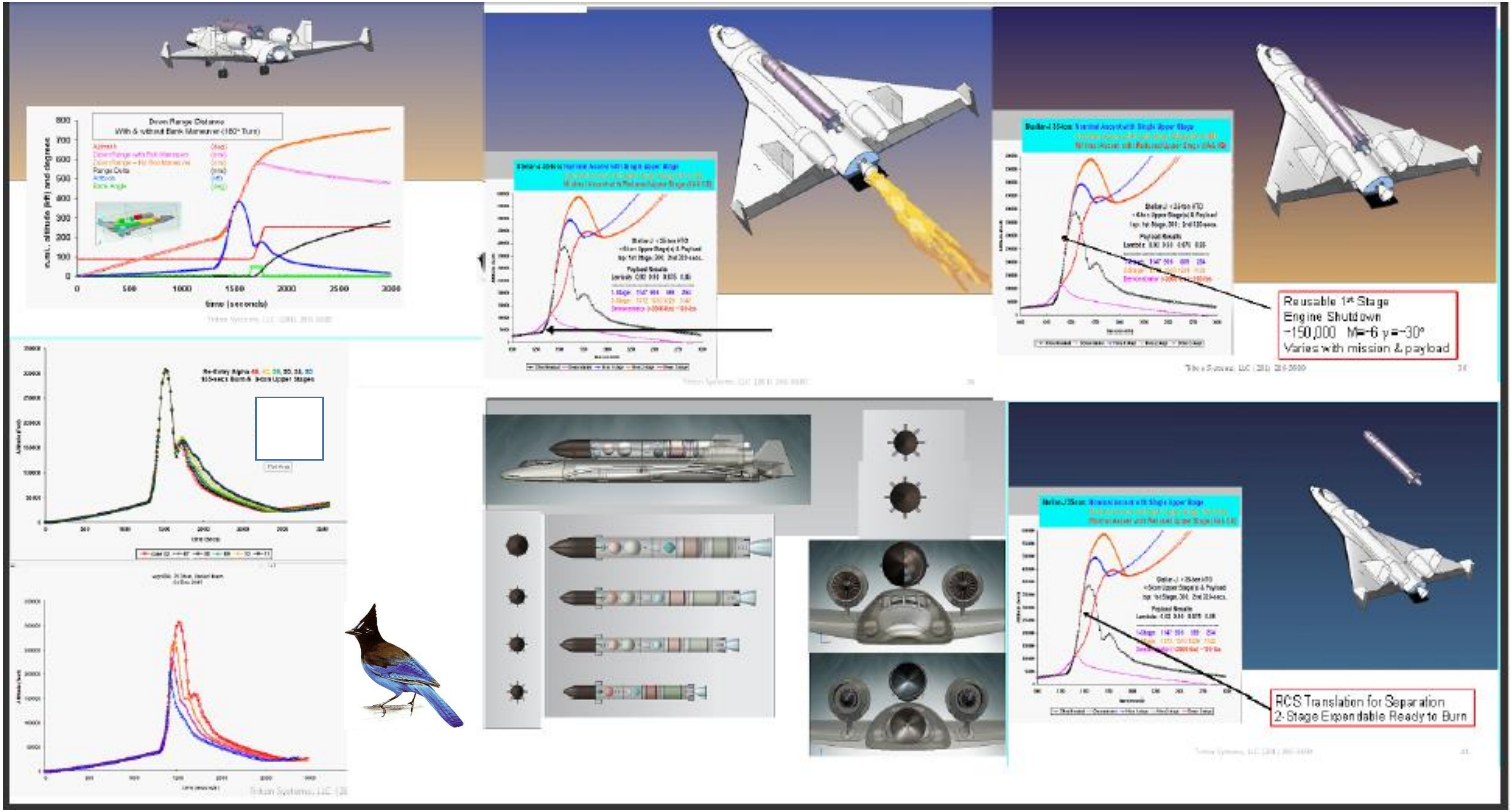
- The history of development of such vehicles from our perspective
- Basic ideas about our launch vehicle obtained
  - Derived from our experience with civil space programs
  - Some of our own characteristic approaches to the problem

- Market considerations and how we identified them
  - Customers or the Community of Users
    - Scalability and Matching Vehicle Variation with Potential Mission, Market and Resources

- Methods Used to develop the preliminary design
  - Launch simulations, Propulsion Analysis, Aerodynamics and Aero Data Bases
  - Structural Studies (In search of the Delta Wing)

- Advancing beyond Preliminary Design
  - Selecting components, partners, suppliers, contacting potential customers.

To relate the way we tie elements together: the effort at integration in design.


Down Range Distance
With & without Bank Maneuver (180° Turn)
time (seconds)
Reusable 1st Stage
Engine Shutdown
~150,000 M=~6 γ=~-30°
Varies with mission & payload
RCS Translation for Separation
2-Stage Expendable Ready to Burn

Stellar-J Elevator Presentation

The Small Satellite User Community

Needs an inexpensive , reliable, launch system that can

- Deploy satellites & turn around fast,
- Grow with user needs,
- Cultivate capabilities for the future such as:
- Rendezvous & Return Cargo

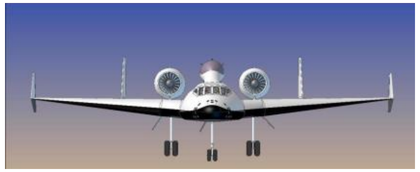
The size of the community, both domestic & foreign, is large:

- Small Companies
- Civil & Military Offices
- Private Research Institutes
- Universities & Related Research Consortia

Its backlog stands at hundreds of satellites in a $20K/lbm payload market.

Our Approach:

Horizontal take and landing first stage with wings and jet engines.



Rocket burn from airline cruise to typical booster rocket staging.

Concept scales from 35 to 350 tons..
Capable of operating at conventional airfields up to jumbo jet facilities….

Stellar-J Launch System:

Horizontal take-off and landing 1st stage with wings & air-breathing engines
Climbs to stratospheric subsonic cruise before igniting
Rocket engines and ascent to hypersonic high altitude burn-out.

Turbofan flight portion removes ~2500 fps from the rocket equation (1 & 2)
Requirement of ~30,000 fps ideal velocity to obtain orbital flight.

Recovering long-lived high- performance rocket engines & 1st stage elements allows:

- Order of magnitude reduction in first stage recurring costs (=> aircraft costs)
- Quick turn-around and frequent access to flight for payloads
- Self-ferrying capabilities and operation to & from air fields with facilities
- Flexible azimuth and inclination adjustments to launch windows
- Modular vehicle design adaptable to several markets (includes suborbital tourism).

Stellar-J Approach Takes "Work" Out of the Rocket Equation

1. Velocity Losses with Altitude:

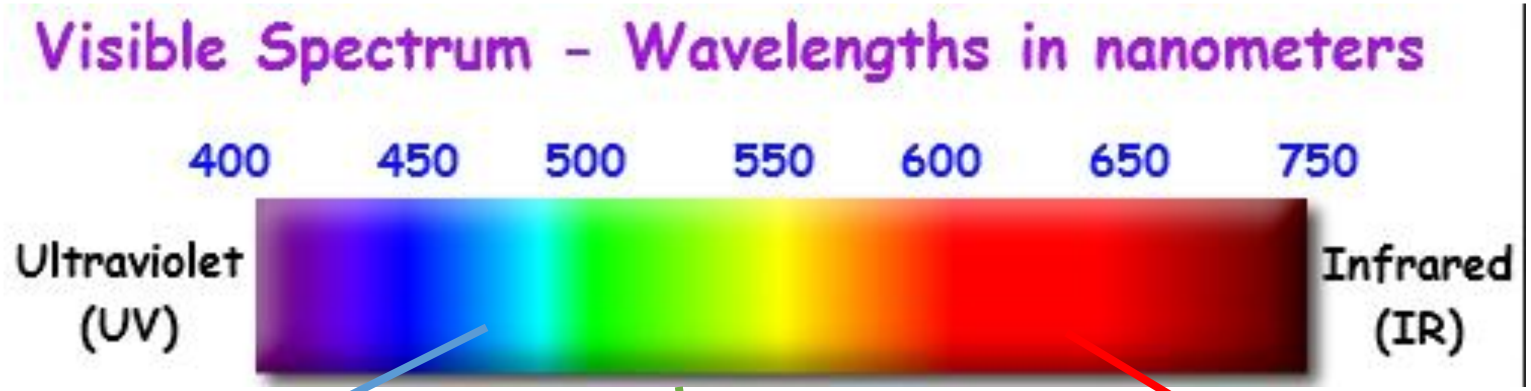
Altitude (ft)	$\sim(2\,g\,h)^{0.5}$ Velocity (fps)
10,000	802
35,000	1,500
350,000	< 4,745

2. Azimuth Velocity

Contributed by Jet Flight
0.7 - 0.9 M at altitude
< 1000-fps

Work2 < Work1

Constant = mv^2 + mg h
TE3 (orbit) = KE3 + PE3 =…
TE2 (flight) = KE2 + PE2 + Work2
TE1 (ground) = KE1 + PE1 + Work1



RESEARCH

DESIGN
&
ANALYSIS

DEVELOPMENT
&
TEST

"If we knew what it was we were doing, it would not be called research, would it?" ‹ Albert Einstein.

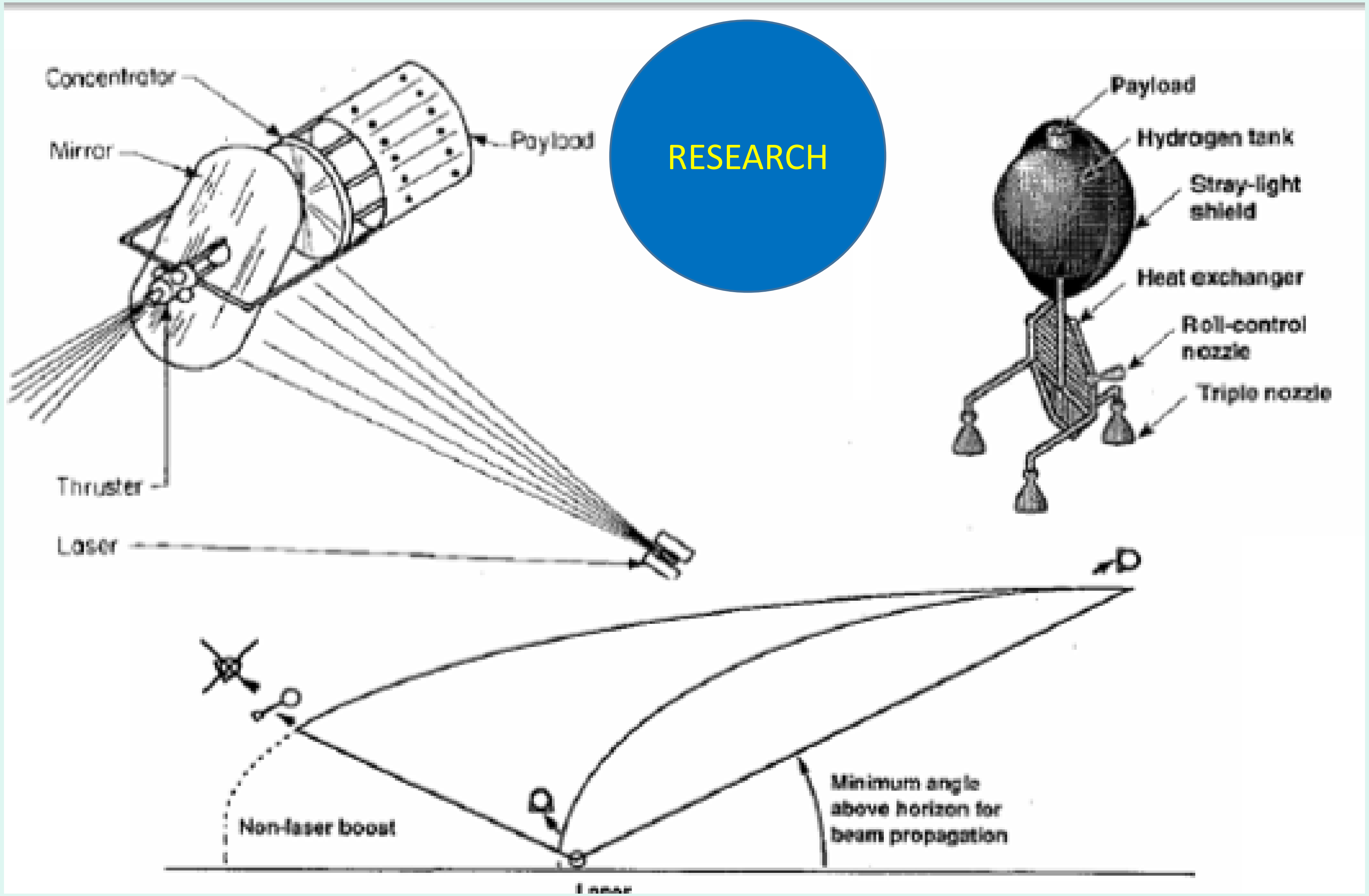
Courtesy of Professor Dave Garrison

“Now see what happens when you change this…”

< Engineers who think they know Where they’re going.

“Let’s take a look at the results and the schedule…”

“Stellar-J to tower…”
< Production.

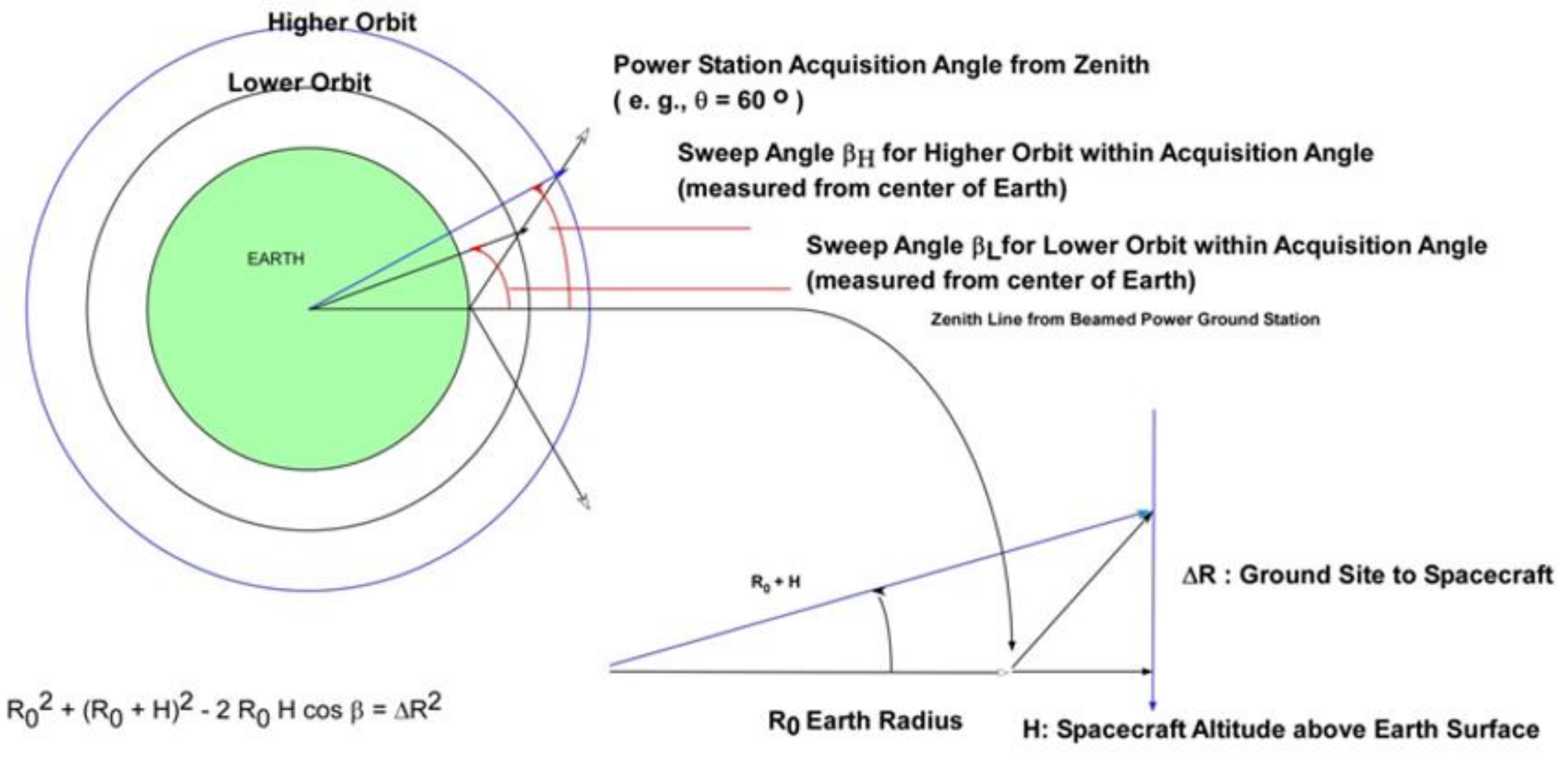


Those are NOT our vehicles.

NASA Glen Research Center
In 2011 was interested in
Beamed Energy Propulsion.

Concepts were based on
laser installations on the
ground or in space focusing
microwave, visible or
infrared radiation on spacecraft
mirrors or concentrators
to provide propellant heating
without combustion
or nuclear energy.

RESEARCH



$R_0^2 + (R_0 + H)^2 - 2\, R_0\, H \cos\beta = \Delta R^2$

Initial β at Acquisition β_0

ΔR changes with $\beta(t) = \beta_0 - \omega\, t$

ω angular rate effected by both orbital rate and Earth rotation

BEAM SPREADS LINEARLY WITH ΔR.

What did that have to do with Stellar-J and Triton Systems?

Triton working as a Subcontractor with the Orbital Technologies team on

NASA Research and Technologies Contract for Aerospace Propulsion Systems (RTAPS)

researched beam energy and examined how Stellar-J Vehicle could be applied

…???

Out of Plane Spacecraft and Rotating Earth, Initially Circular Orbit

$\underline{X}_1$ = Beamed Power Ground Site

$\underline{X}_2$ = Orbiting Spacecraft (assumed circular (initially)

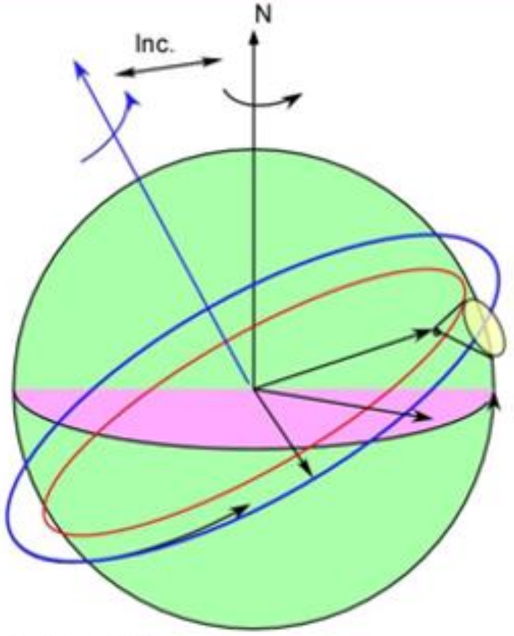
$$\underline{X}_1 \circ \underline{X}_2 / |X_1|\,|X_2| = (x_1 x_2 + y_1 y_2 + z_1 z_2) / [R_0 (R_0 + H)]$$

$$\underline{X}_1 = R_0 (\cos\alpha_{R1} \cos\delta_{R1}, \sin\alpha_{R1} \cos\delta_{R1}, \sin\delta_{R1})$$

$$= R_0 (\cos\lambda(t) \cos\phi E, \sin\lambda(t) \cos\phi_E, \sin\phi_E) \text{ where } \lambda = \lambda_0 + \omega_E t$$

$$\underline{X}_2 = (R_0 + H)(\cos\alpha_{R2} \cos\delta_{R2}, \sin\alpha_{R2} \cos\delta_{R2}, \sin\delta_{R2})$$

$$= (R_0 + H)(\cos\Omega \cos\theta^* - \sin\Omega \cos i \sin\theta^*, \sin\Omega \cos\theta^* + \cos\Omega \cos i\, s\, \theta^*, \sin i \sin\theta^*)$$

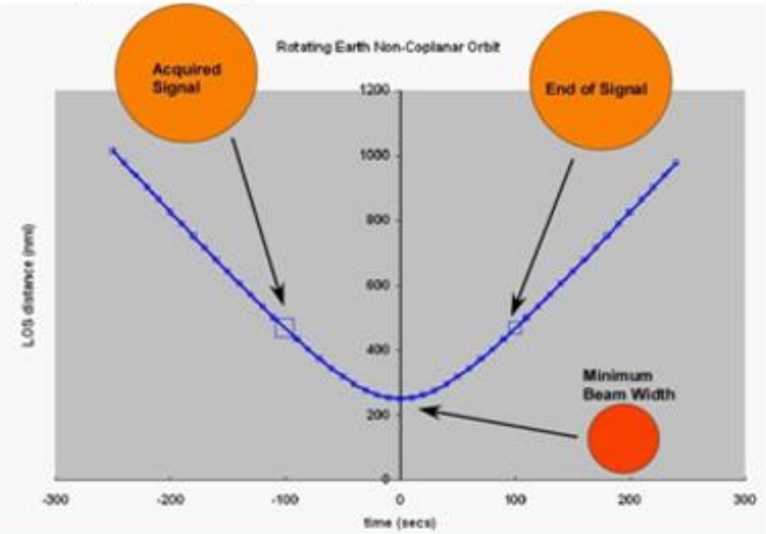


α_R, δ_R : celestial coordinates right ascension and declination for unit vectors 1 and 2.

i : inclination

Ω: ascending node, corresponding to right ascension position of orbit crossing northward

θ^*: for circular orbit, great circle arc from ascending node



RESEARCH

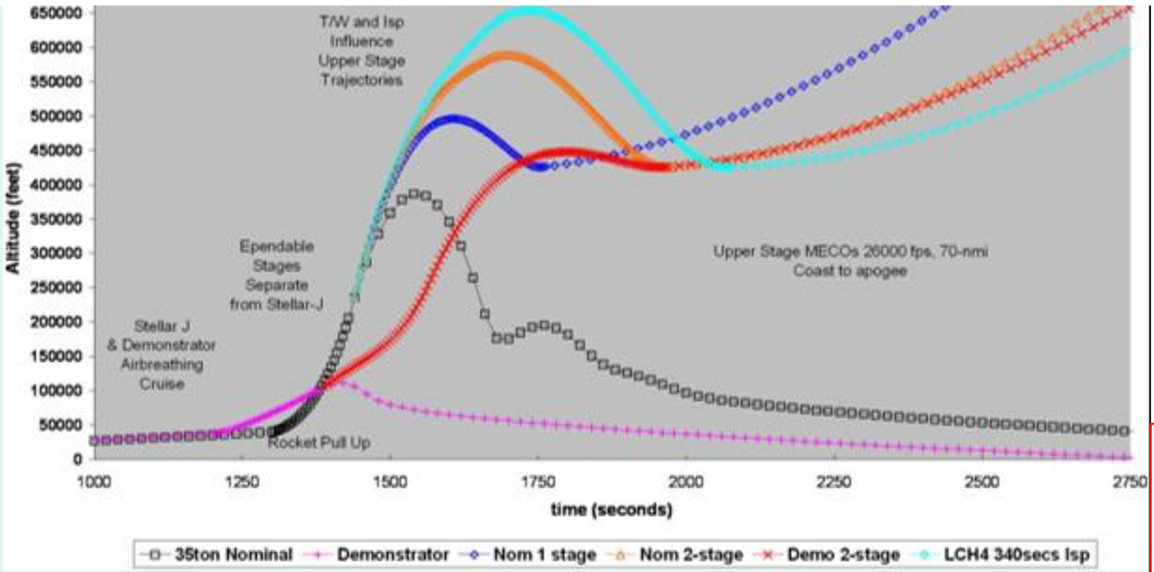
Whether laser beam source in space or on the ground
geometric constraints & attenuation affect power delivery.

For ground-based case,
orbital window limited by overflight & nodal regression.

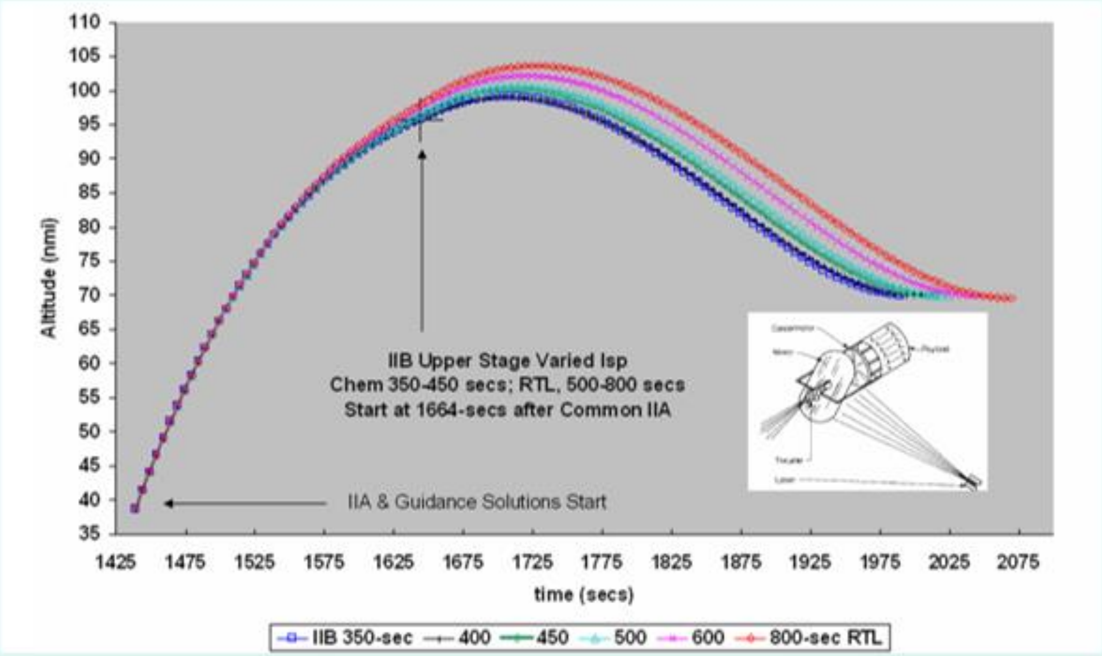
But on ascent, activity is also geographically limited.
Could beamed energy power an upper stage?

Upper Stage Ascent Profiles
High & Low ("Demo) Energy
RLV First Stage Ascents
Single and 2-Stage Expendables
Higher Specifc Impulse (CH4)
Lofts ascent flight path.

Nominal RLV Stage
Demonstrator RLV Stage
Demonstrator 2-stage Expendable
Nominal Single Expendable Upper
Nominal 2-Stage Expendable
LCH4 –fueled 2nd Stage

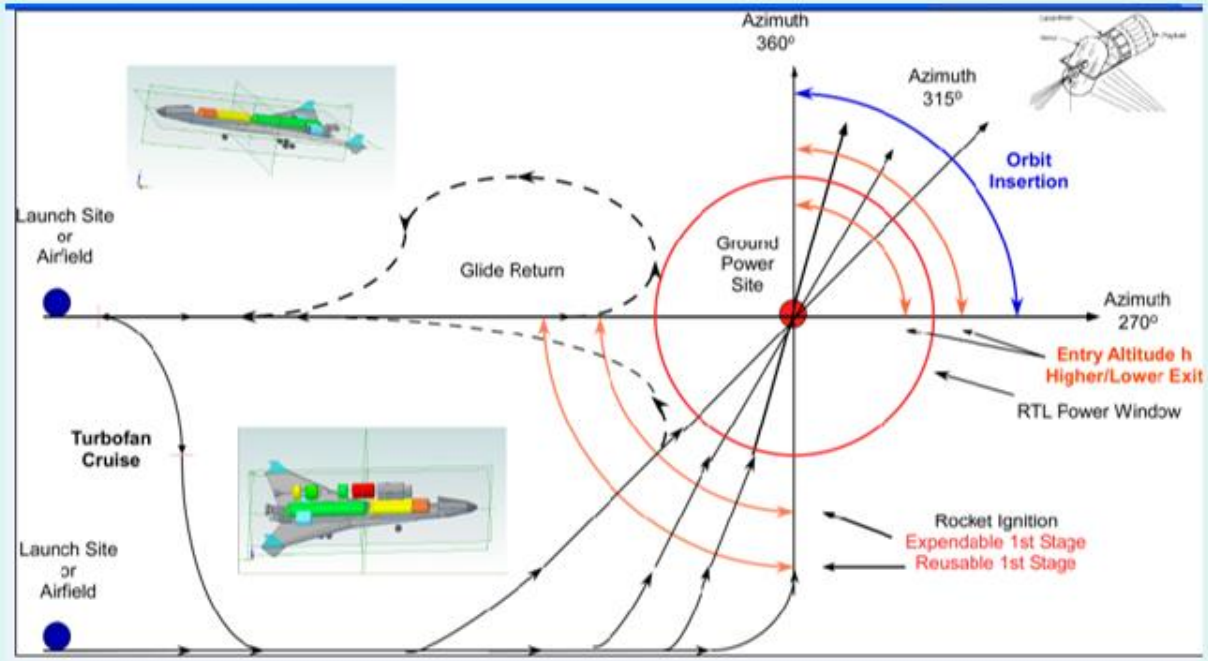


Beamed Energy Constant Thrust
Upper Stage Time-Altitude Profiles
Compared to Nominal Chemical
Engines 350, 400, 450-sec
Specific Impulse .
Beamed Energy Cases:
500, 600, 800-secs.

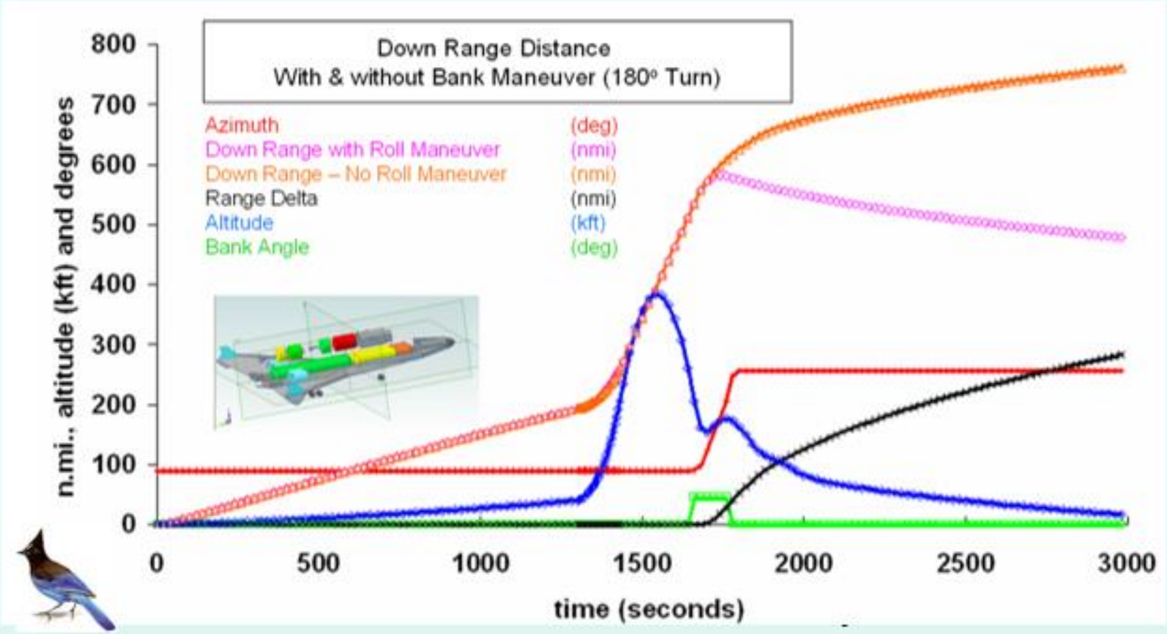


RESEARCH

Specific impulse (ISP)
could be higher than
Chemical systems
(500 to 800 seconds
Vs 300 to 450),
buthow much power
is needed for equivalence
in thrust
to a chemical engine?



1st Stage winged RLV
(Reusable Launch Vehicle}
Flies out from launch site,
deploys expendable upper stages
with terminal stage flying over
G/S beam energy site.



1st Stage RLV
Time- Altitude Profile
Down-Range Distance
With & without
Banking Turn

RESEARCH

Table 1.3 Stellar-J Terminal Weights Based on 2nd Stage Scaling and Isp Variations
Actual Payloads To Be Determined Based on Stage Mass Fraction λ_{stage2}

$m_{IIA} + m_{IIB} + m_{PL}$ **Separation Weight: 12,000-lbs** m_{IIB} = 4160-lbs Thrust = 2610-lbf

I_{SP}:	**320**	**350**	**400**	**450**	**500**	**600**	**800-secs**
Final:	1602	1772	1929	2095	2238	2478	2811-lbm
Power:	-	-	-	-	**56.9**	**68.3**	**91.1-MW**

$m_{IIA} + m_{IIB} + m_{PL}$ **Separation Weight: 4,000-lbs** m_{IIB} = 1386-lbs Thrust = 870

I_{SP}:	**320**	**350**	**400**	**450**	**500**	**600**	**800-secs**
Final:	534	590	643	698	746	826	937-lbm
Power:	-	-	-	-	**19.0**	**22.7**	**30.4-MW**

Stage IIB I_{SP}(secs):	320	350	400-450	**500-800**
Fuel & Oxidizer	Kerosene-LOX	CH4-LOX	LH2- LOX	LH2
Chemical Combustion	X	X	X	
Beamed Energy				**X**

For various thrust and specific impulse levels equivalent megawatt Full efficiency power,

Power received at the spacecraft in **blue bold**.

Receiver technology: TBD

The preceding account is a “research anecdote” about examining a new vehicle concept.

But it demonstrates possibilities for the launch system based on its versatility and potential adaptability:

1. Capability of launch from a runway and flight out to various headings or azimuths.
   This not only allows acquisition of various orbital inclinations and ability to match tracks for rendezvous, it also allows over flight over specific geographic features.

2. The expendable upper stage system base-lined as 2-stages (IIA & IIB) provides a simple common boost element (IIA) and an adaptable mission oriented terminal stage (IIB) trading propellant, payload and bus features.

We will talk more about other features in the following sections.

DESIGN
&
ANALYSIS

Subsequent material from presentations
Will be re-examined from an instructional perspective.

Sequence

Computer Tools: Some Discussion about means developed to obtain initial analyses.

Computer Output in Plots: Vehicle Characteristic Behaviors and Variations

Vehicle Layout: Moving out in all directions from examinations of simple trajectories elaborating on

- mass properties and transformations in phases of flight
- aero and thermodynamics,
- control systems (flaps and thrusters) and stability analysis
- materials responding to stress and stain
- hardware selections such as jet engines…

DESIGN & ANALYSIS

Accommodating Missions and Markets **(Optional/Questions)**

Establishing Criteria for Trades **(Optional/Questions)**

Home

The Program to Optimize Simulated Trajectories II (POST2) is a generalized point mass, discrete parameter targeting and optimization program. POST2 provides the capability to target and optimize point mass trajectories for multiple powered or unpowered vehicles near an arbitrary rotating, oblate planet. POST2 has been used successfully to solve a wide variety of atmospheric ascent and entry problems, as well as exoatmospheric orbital transfer problems. The generality of the program is evidenced by its multiple phase simulation capability which features generalized planet and vehicle models. This flexible simulation capability is augmented by an efficient discrete parameter optimization capability that includes equality and inequality constraints. POST2 supports NASA's Strategic Goal to expand the frontiers of knowledge, capability, and opportunity in space by directly contributing to expanding our human and robotic presence into the solar system and to the surface of Mars as well as other planetary bodies.

Others

SORT: Space Optimization of Rocket Trajectories
OTIS: Optimization of Trajectories by Implicit Simulation…
SVDS: (Historical: Shuttle Vehicle Dynamic Simulation: 6DOF & GN&C)
We developed a family of our own: For reasons to become apparent
LAUNCH, AEXTRAP… (Progenitors for ballistic launch, orbital finite burns, propulsion trades)
JETFJ… 1, 2, 3, … 6, 7 - Working tools for HTOL with wings & jet engines

Trajectory Simulations Concentrate on Paths, Not Design.

Ascent Simulations: Numerical Integration & Optimization Methods, Largely for 2-Point Boundary Problems.

Simulations with Rocket & Jet Engines (with wings) grew Up in separate homes.

Multi-Discipline Optimization?

Research

F:\AI9112~1\JETFJ17.EXE

INPUT DATA

```
? 1.

 First data case is default.
 Enter # to select subsequent cases.
iconf,   wgt0i,  tmagi,   neng,   cisp,    vex,    S,   akf
tmagrk,  cispv,  cispsl,  wjetf,  rprop, ustwgt, isp, thrst
toffjt,  tonrk,  toffrk,  pitrtc, pitchi,  alphae, nrock
iiab , fuel 1-3, clm2ai, clm2bi, uisp2bi, thrs2bi, payl0di, xmri1, xmri2, xmri3
icode, wingldi, Wareai, clmbLEi, clmBTEi, hspani cti, cri, ctcr

 Nominal 1 NK-31, 2 BMR710s, Upper Stage,          L/D = 5.91
  1  68000.0 20000.0    2 7200.00 2500.00 1094.00  1.0000
     90000.0  335.00  278.54   8000.0  36000.0  12000.0  300.0    9600.0
   1350.0    1300.0    1435.0      .100      18.0      45.0    1
  1   1   2   1     .8500    .8917   320.00  1305.00   300.00 2.60 1.60 2.20
  1     42.00  1639.00    45.00      .00    420.00    72.00    490.00     .0000

 Nominal 1 NK-31, 2 BMR710s, Upper Stage,          L/D = 5.91
  2  68000.0 20000.0    2 7200.00 2500.00 1094.00  1.0000
     90000.0  335.00  278.54   8000.0  36000.0   6000.0  300.0    4800.0
   1350.0    1300.0    1435.0      .100      18.0      45.0    1
  1   1   2   1     .8500    .8917   320.00  1305.00   300.00 2.60 1.60 2.20
  1     42.00  1639.00    45.00      .00    420.00    72.00    490.00     .0000
?
```

```
?

Trajectory Initial, Intermediate & Terminal Conditions
 Event       Time  Altitude   Vrel   Gamma   Vinert    Weight  Latitude   Az   Alph
Take-Off :     0.     100.   311.3    .000   1645.9   68000.0    29.00   90.0  10.5
10,000 ft:   481.   10005.   949.2   1.707   2284.4   67213.9    29.00   90.0   3.2
35,000 ft:  1168.   35015.   806.0   3.178   2142.9   66462.9    29.00   90.0   6.0
Ignition :  1300.   40924.   703.7   3.583   2041.0   66362.7    29.00   90.0   8.7
Shut-down:  1390.  106941.  3757.3  22.797   5098.7   42365.9    29.00   90.0   4.1
Apogee   :  1464.  165391.  2902.8    .216   4247.9   32343.5    29.00   90.0  27.2
NZ max   :  1302.   41138.   763.8   6.784   2101.0   65756.0    29.00   90.0   9.1
25k Start:  2700.   25005.   962.9   1.325   2299.1   32063.0    29.00   90.0   1.8
T-final  :  3400.   46840.   936.7   2.599   2274.3   31535.8    29.00   90.0   3.0

              Additional Minima and Maxima
Qmax     :   115.    1189.   964.4   1.018   2299.1   67777.4    29.00   90.0   2.9
Qmax burn:  1343.   58756.  2011.4  19.909   3349.7   54724.7    29.00   90.0   2.3
Qmx entry:  1390.  108393.  3738.4  22.825   5079.9   42097.2    29.00   90.0   4.2
qdot up  :  1389.  106941.  3757.3  22.797   5098.7   42365.9    29.00   90.0   4.1
qdot down:  1520.  135450.  2819.5-18.148   4162.8   32343.5    29.00   90.0  25.0
?
MECO state initiates upper stage sequence.
```

Representations of Nominal Trajectories

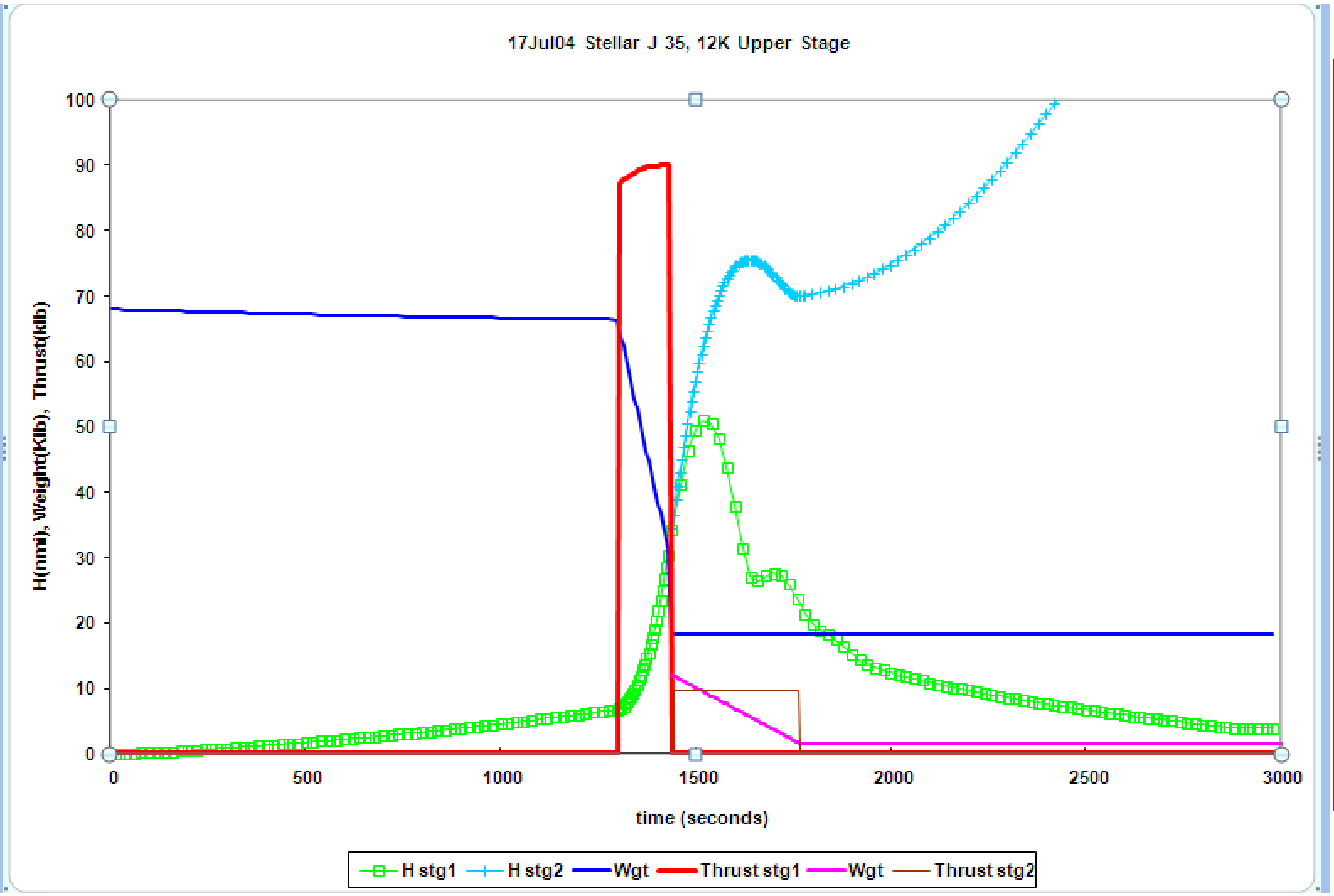
PLOT PACKAGE VARIABLES >>

```
? 1.
                    PLOT VARIABLES

 1 Time (seconds)       2 Altitude (feet)
 5 Gam Rel.   (deg)     6 Alpha
 9 Down Range (nmi)    10 Jet thrust(h,v)
13 Lift accel.         14 Drag accel
17 Wgt per SFC         18 Wdot (lb/sec)
21 Q-bar (lb/ft**2)    22 Q*alpha
25 sensed accel        26 sens acc. dir.
29 x (ft)              30 y (ft)
33 ydot (fps)          34 zdot (fps)
37 Temp adia wall      38 Temp (R) amb
41 Qload tot           42 Elevator deflect
45 Cm(M,alpha,cg)      46 Cl (mach,alpha)
49 al(3)               50 Wingload lb/ft^2

  3 V-relative (fps)    4 Mach Number
  7 Pitch    (deg)      8 Weight (lbs)
 11 Rocket thrust      12 Grav acc(fps**2)
 15 Thrust accel       16 Jet Vex (fps)
 19 Normal load        20 taccel
 23 qdot               24 qdot-btu/ft2/sec
 27 latitude   (deg)   28 phi (bank)
 31 z (ft)             32 xdot (fps)
 35 az(f(t))           36 Temp eq wall
 39 Qload up (btus)    40 Qload down
 43 cg in flight       44 Cm (mach,alpha)
 47 al(1)              48 al(2)
 51 p ambient
```

<< 1st STAGE SUMMARY



Illustrative Flight Parameters

First Stage Ascent Altitude (kft)

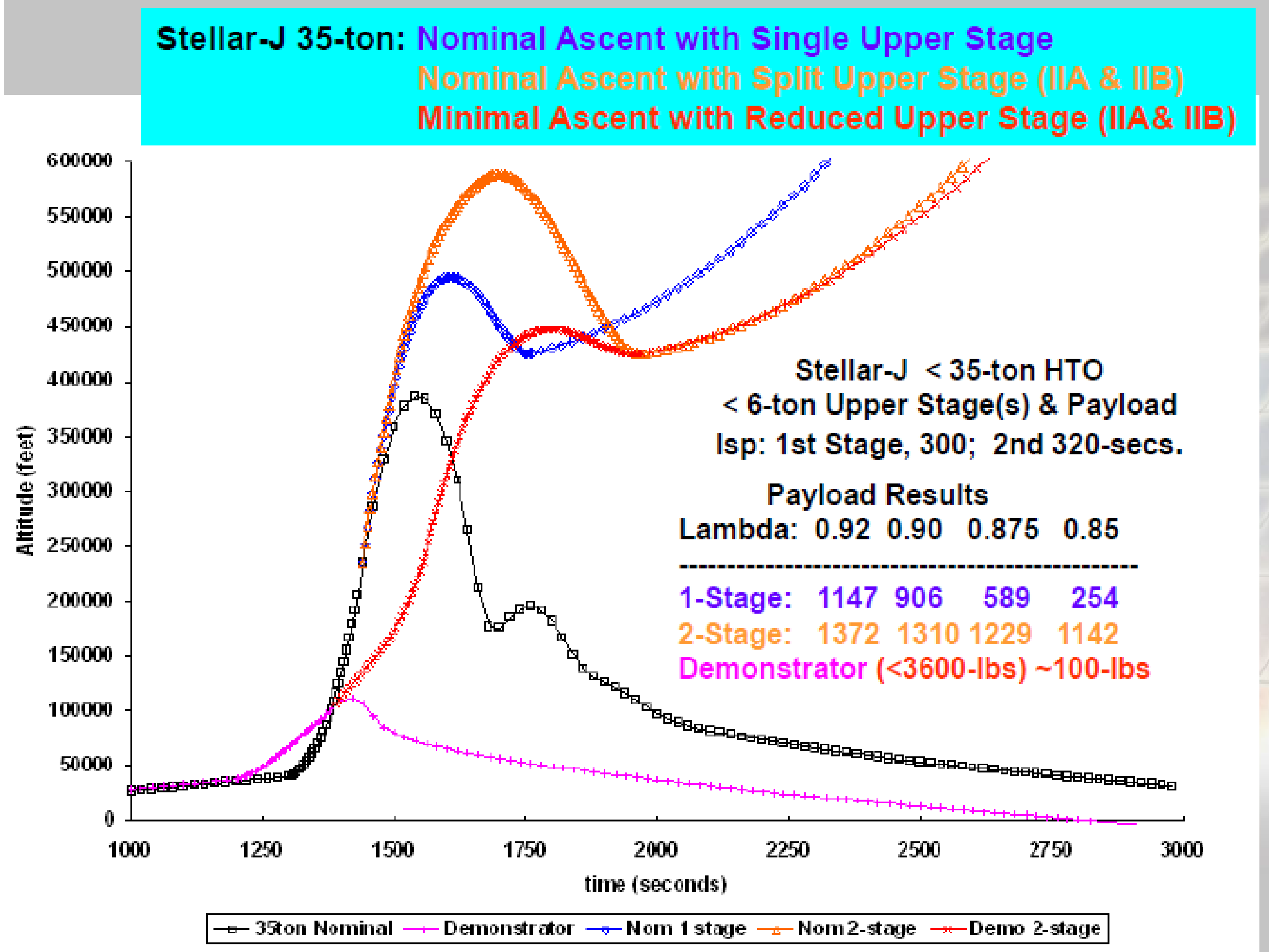
Expendable Upper stage Altitude (kft)
- single stage

1st Stage Rocket Engine Thrust (klbf)

Weight of 1st Stage (klb)
- with & without upper stage
- no jet re-start

Expendable Upper Stage Thrust (klbf)

Expendable Upper Stage Wgt ((klb)



For the 1st Stage winged, reusable component of the Stellar-J, climb-out from subsonic stratospheric flight under rocket power exerts both mechanical & thermal loads.

Mechanical loads gather near the wing roots (discussed elsewhere).

Thermal loads concentrate at leading edges and tips.

Results for Thin Surfaces:
Upper & lower tip chord leading edges of wings vertical tails and winglets subject to highest Temperatures at highest Thermal fluxes dq/dt (BTU/sec/ft2).

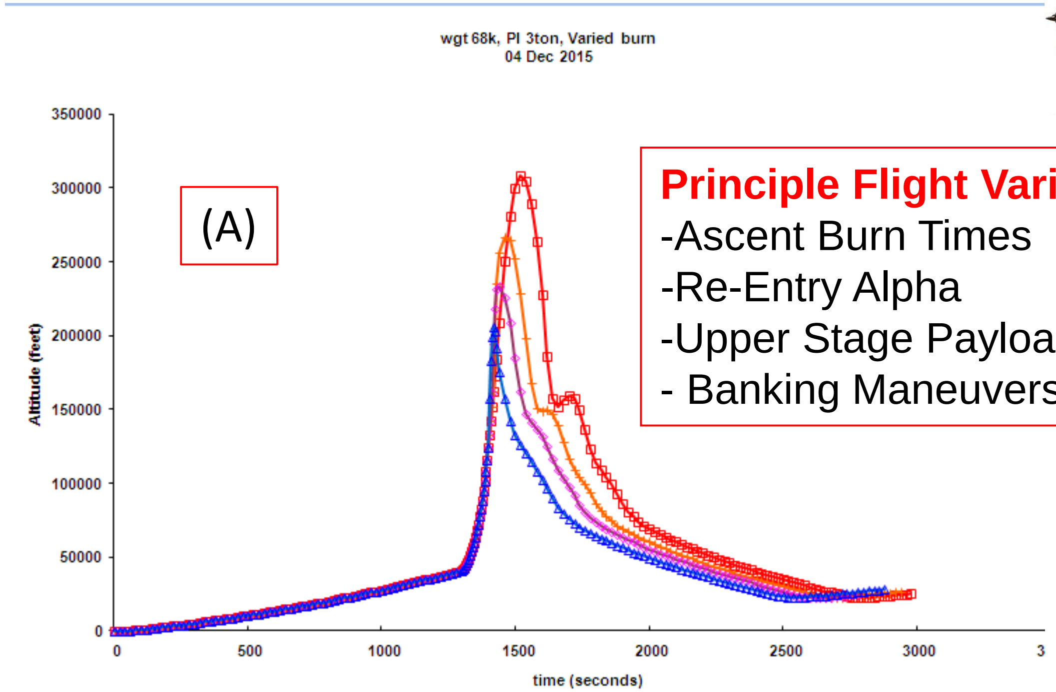
Upper Stage Separation Wgts
Based on a nominal value.

Margin Dependent on Wing Design

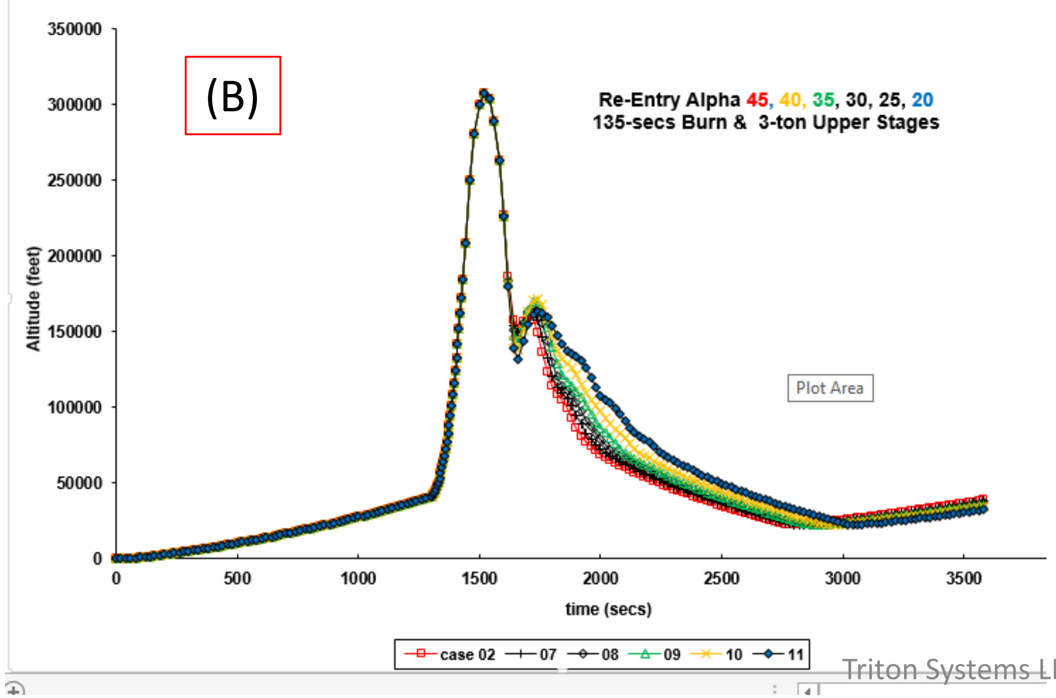
Principle Flight Variations

- -Ascent Burn Times (A)
- -Re-Entry Alpha (B)
- -Upper Stage Payloads (C)
- - Banking Maneuvers (D)

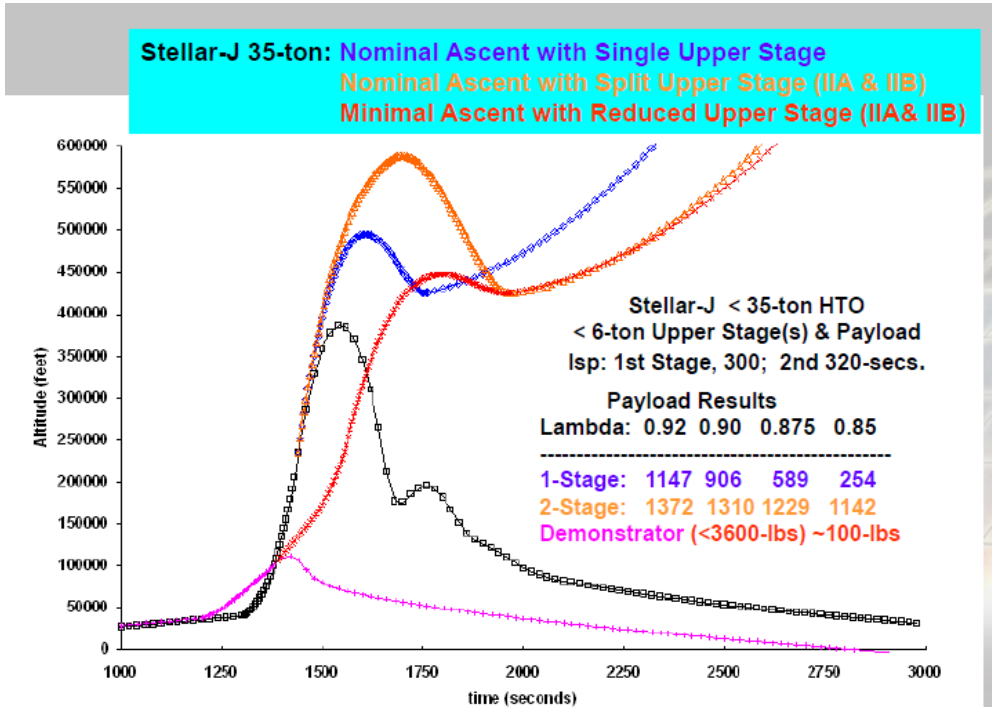
(A)



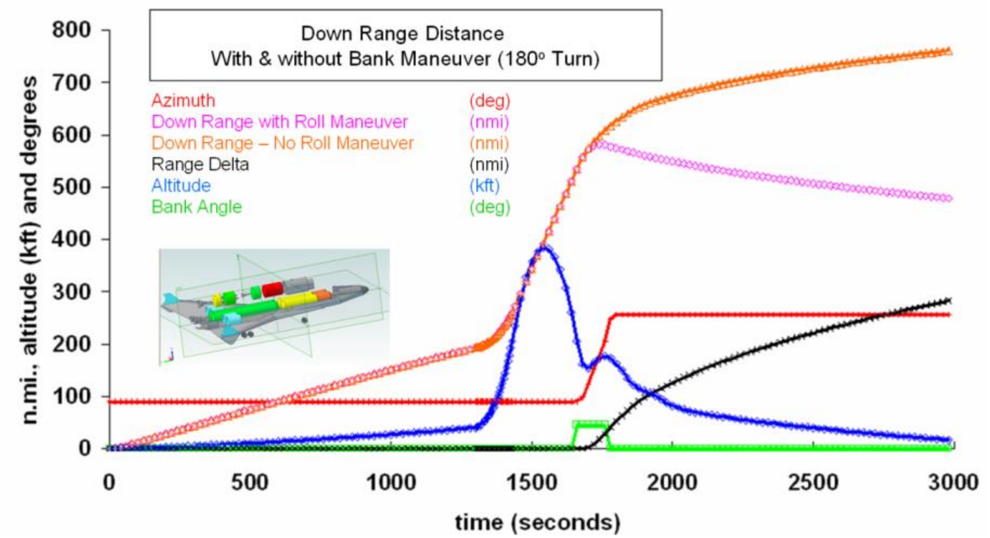
(B)



(C)



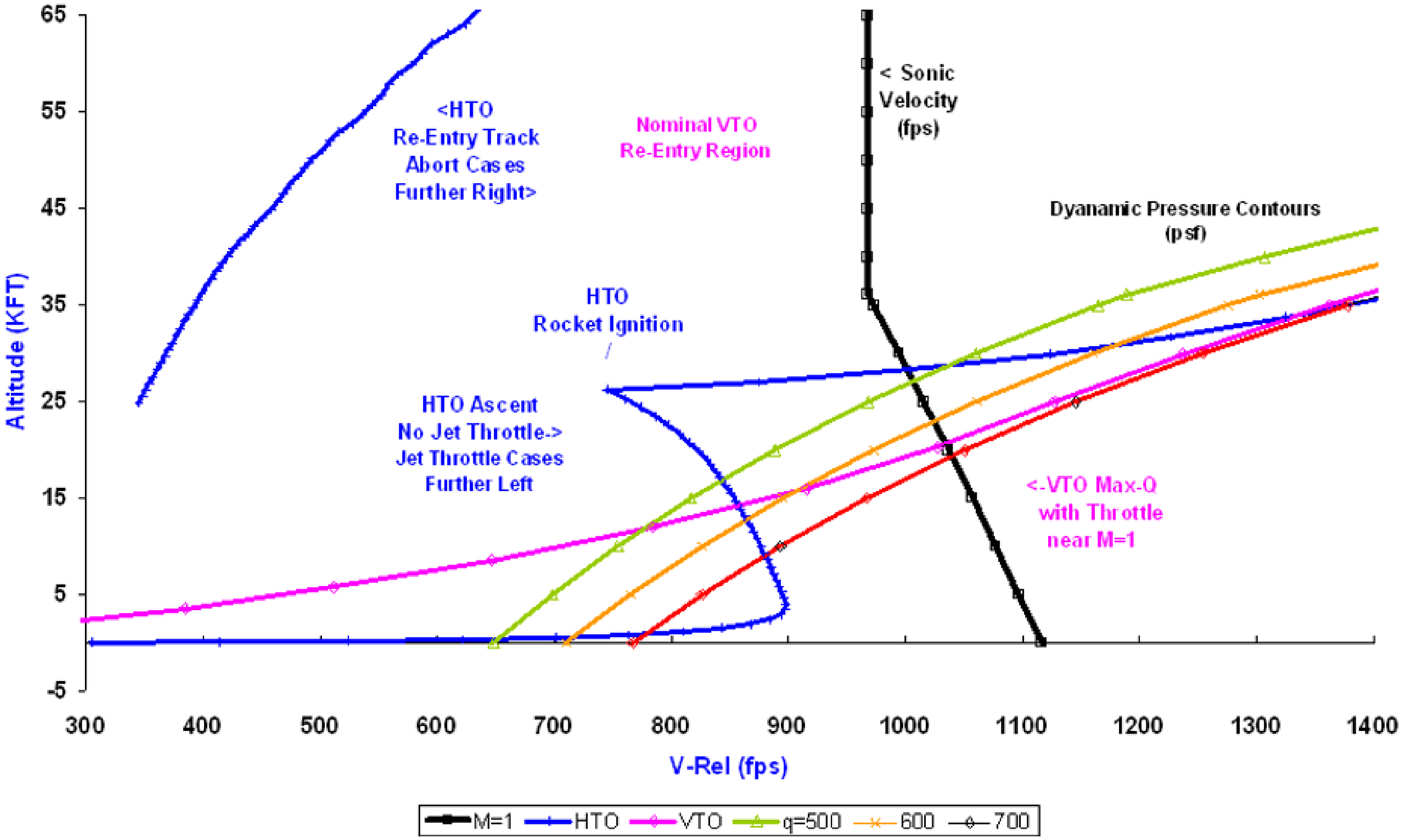
(D)

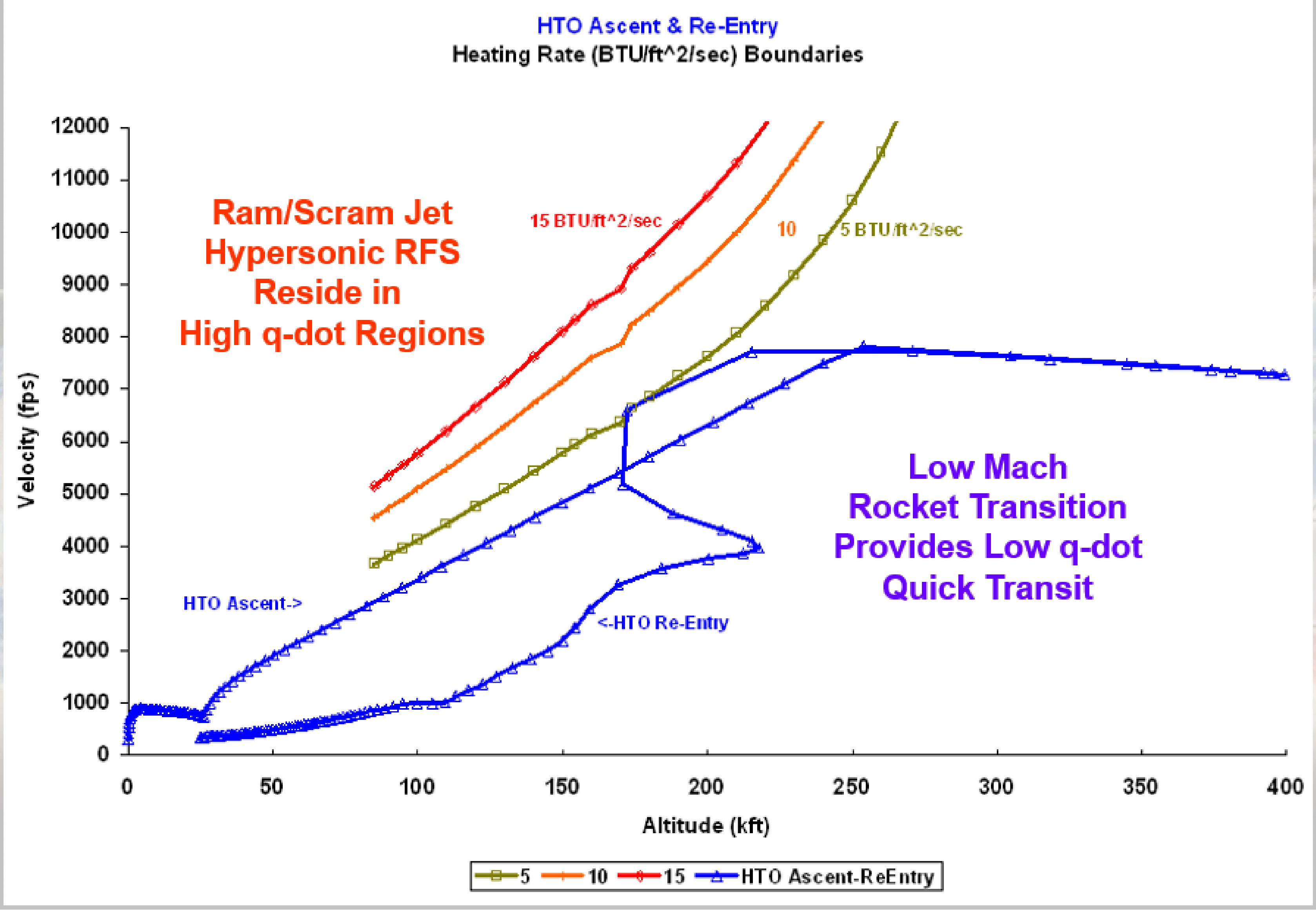


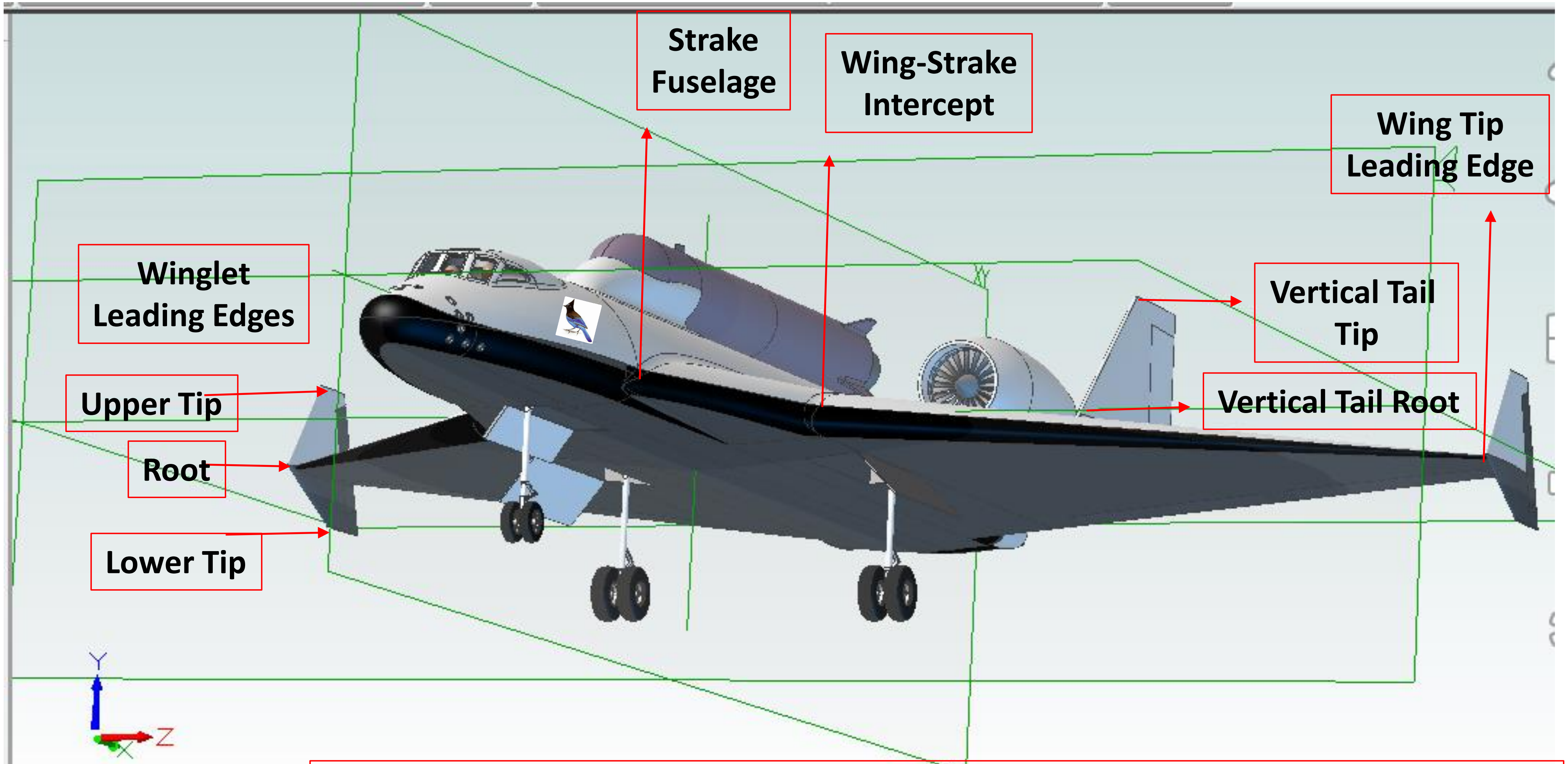
Performance Envelope Analysis: Altitude, Q, Velocity, Mach

VTO Max Q Modulated by Rocket Throttle
VTO (T/W)o Determined by Pad Clearance

Early Max Q on HTO Alleviated with Jet Throttle
Secondary Max Q – No Rocket Throttle Required
HTO $(T/W)_0$ Lower – Different Engine Out Criteria

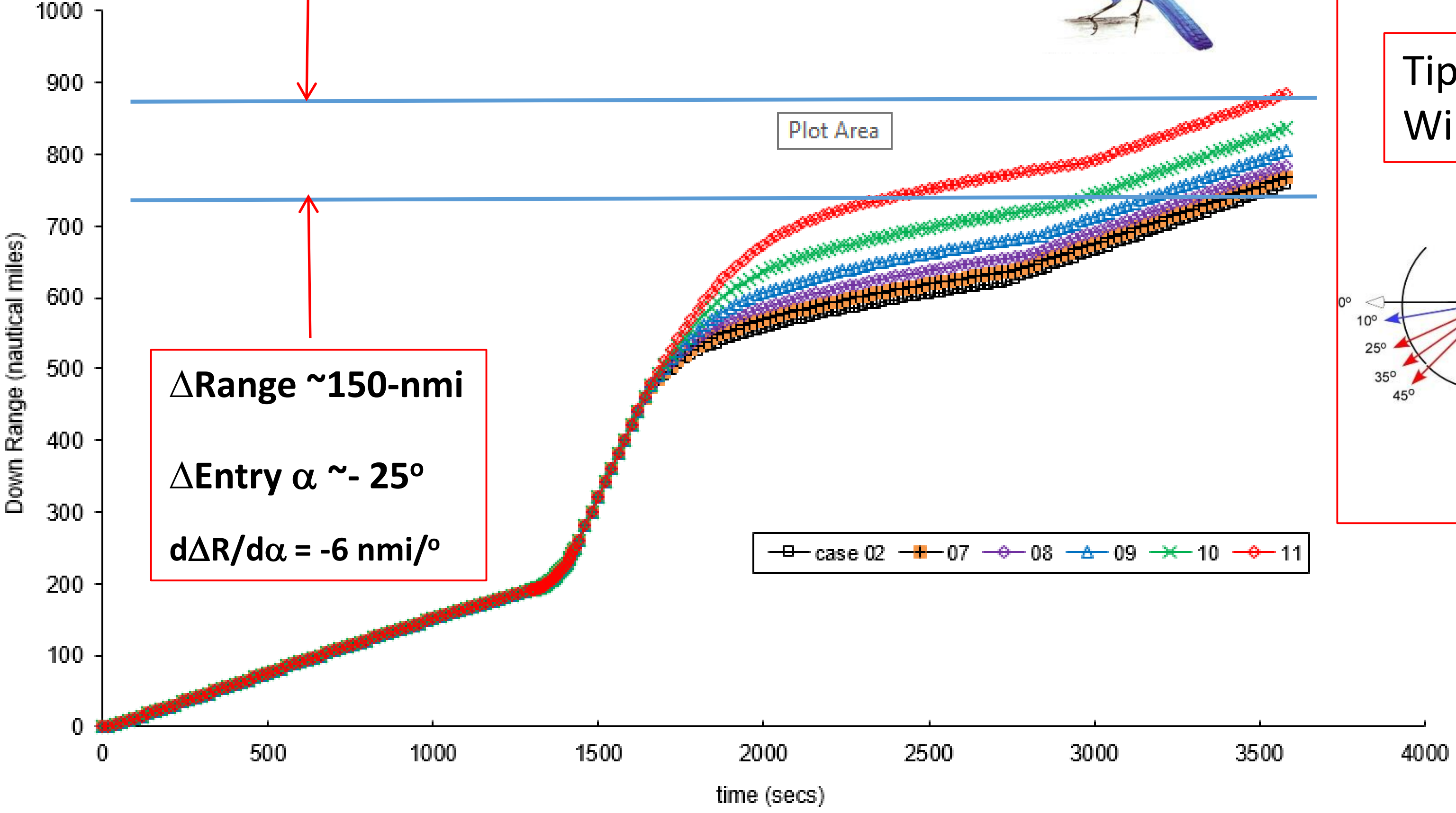



HTO Ascent & Re-Entry
Heating Rate (BTU/ft^2/sec) Boundaries
Ram/Scram Jet
Hypersonic RFS
Reside in
High q-dot Regions
15 BTU/ft^2/sec
10
5 BTU/ft^2/sec
Low Mach
Rocket Transition
Provides Low q-dot
Quick Transit
HTO Ascent->
<-HTO Re-Entry
Velocity (fps)
Altitude (kft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
0
50
100
150
200
250
300
350
400
5
10
15
HTO Ascent-ReEntry



Earlier work examined external wing component geometry, & aero-thermodynamics

Re-Entry Alpha **45°**, **40°**, **35°**, **30°**, **25°**, **20°**
1350secs Burn & 3-Ton Upper Stage System

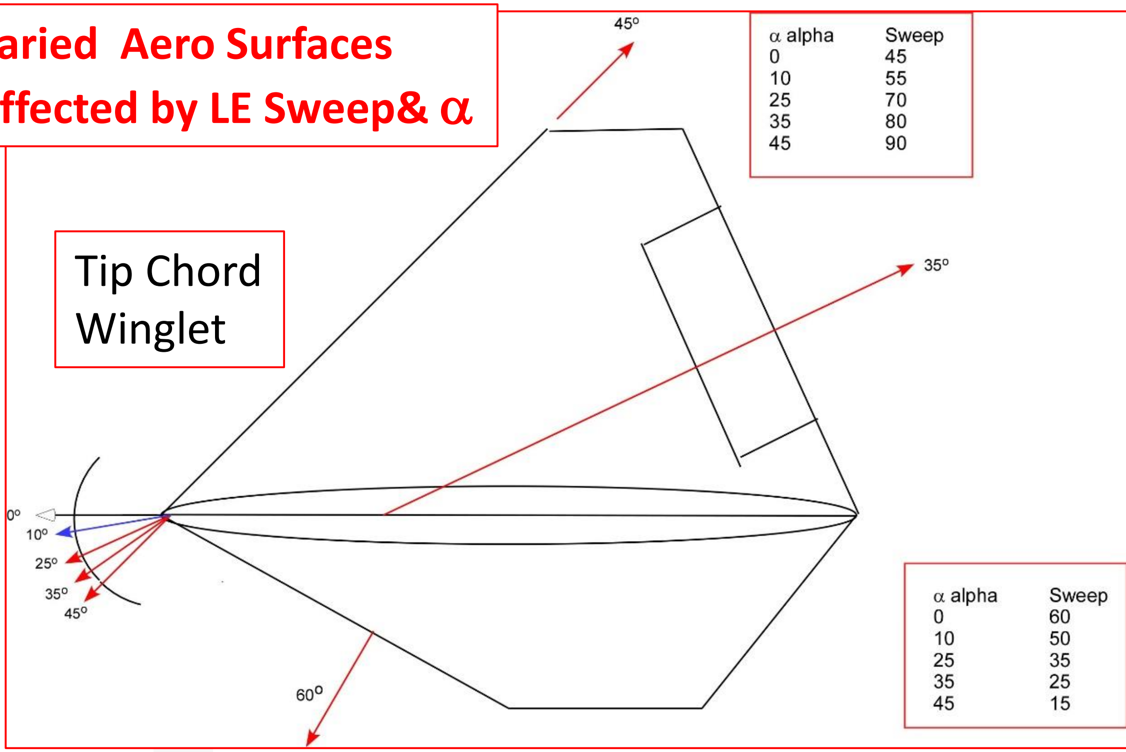


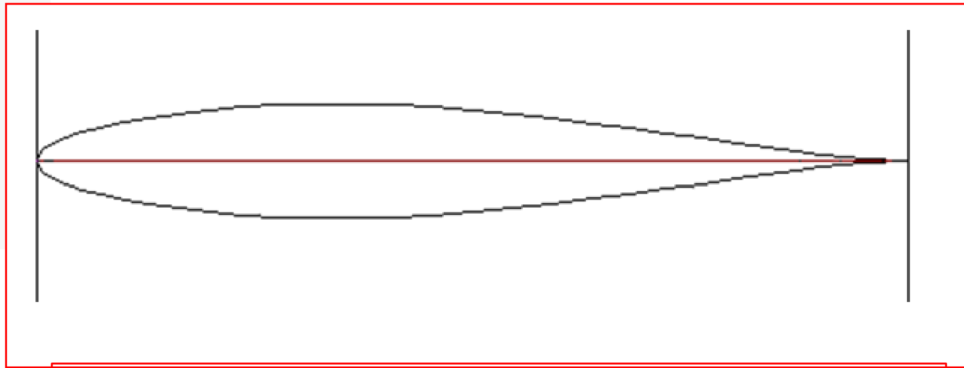
ΔRange ~150-nmi

ΔEntry α ~- 25°

dΔR/dα = -6 nmi/°

Varied Aero Surfaces
Affected by LE Sweep& α

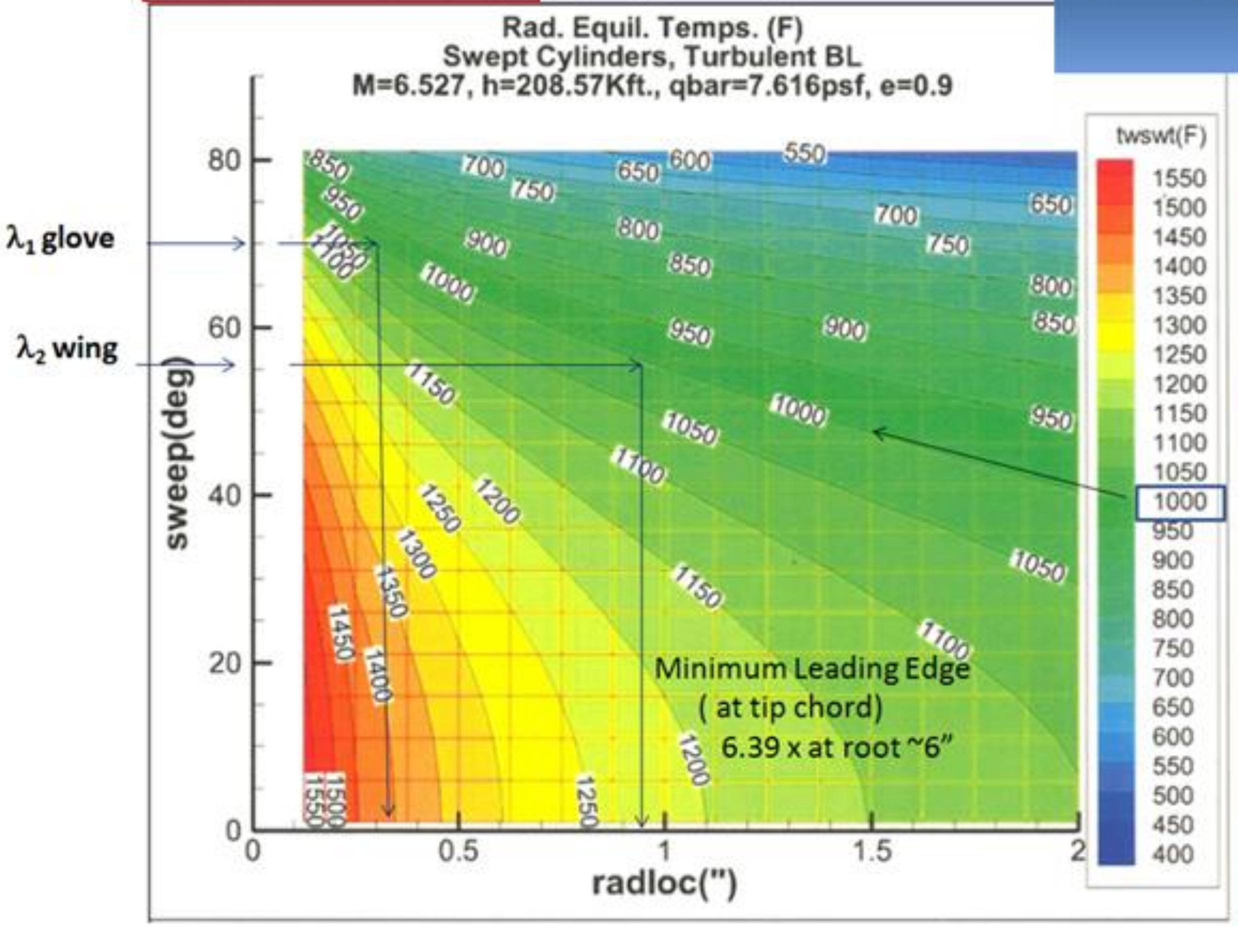


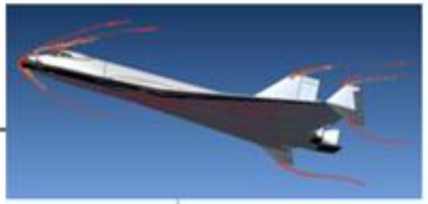


Typical Thick Symmetric Vertical Tail Airfoil

RE-ENTRY ANGLE OF ATTACK EFFECTS OVERALL RANGE

Aero-thermal Heating





Stellar-J
Design Reference Mission
Ascent & Re-Entry
Peak Heating Conditions

Illustrative Stagnation Temperatures Associated with Leading Edge Features

1000° F contour Temperature Selected to illustrate limits at glove (strake) & swept wing.

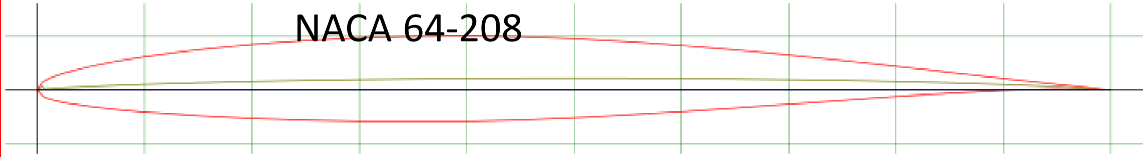
High sweep glove close to fuselage, Probably bulged for wing root spars & Utilities vs. low required radius.

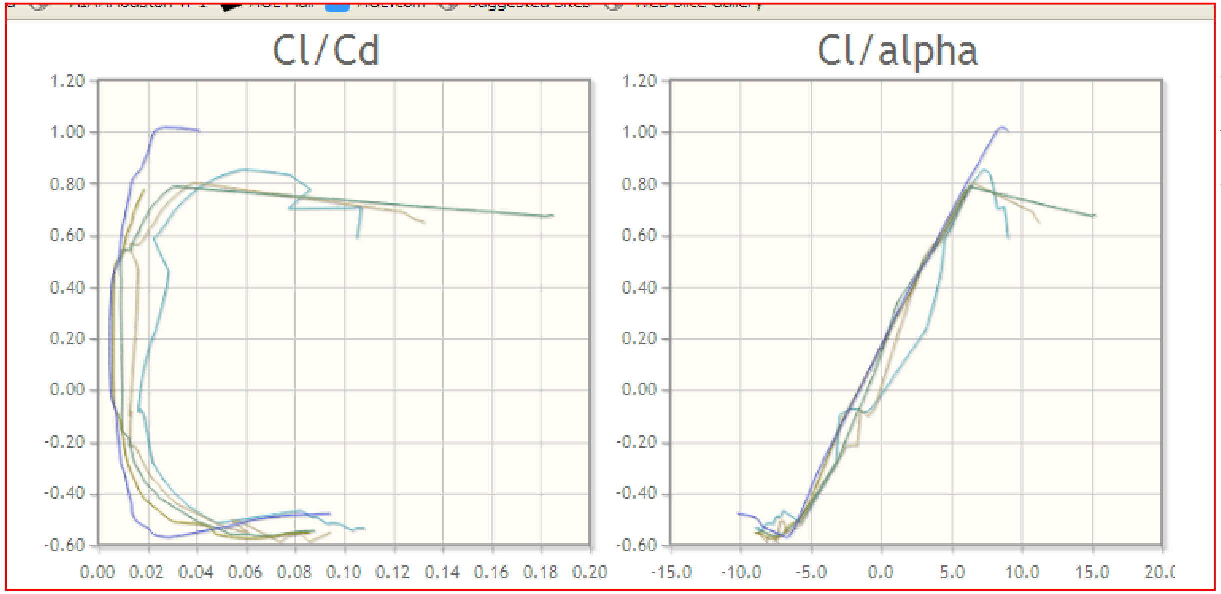
Outboard taper could bring Stagnation temperature to high levels Particularly close to tip chord & Winglets.

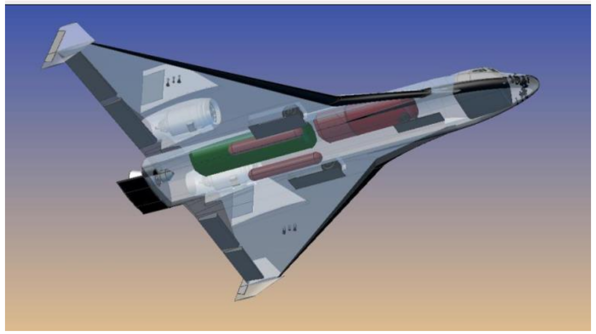
Curves Beg Question:
Are there Empirical Relations?

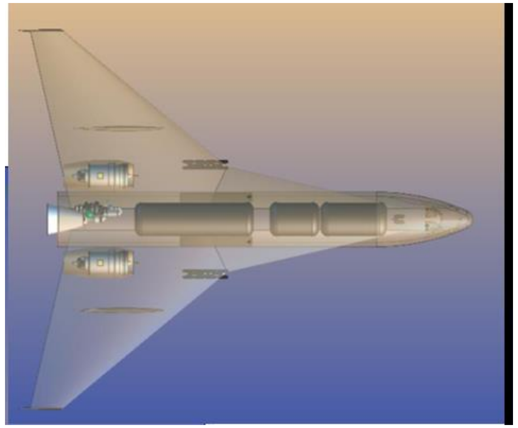
7

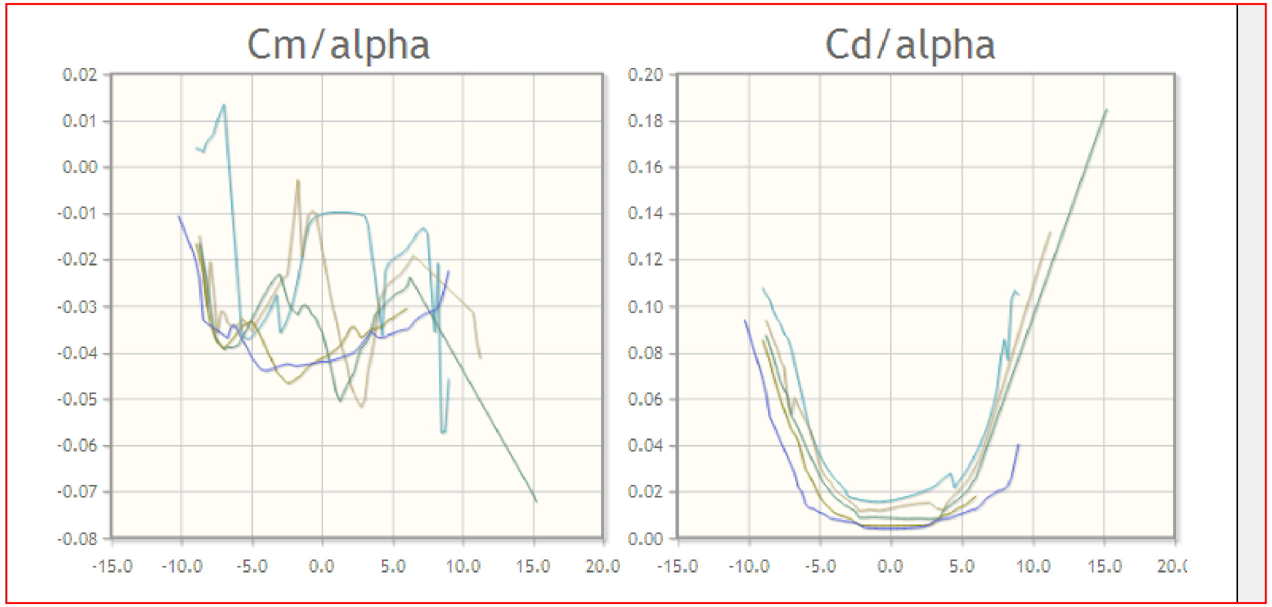
Nominal Stellar-J Selection (+ Trades)











lars for NACA 64-208 (naca64208-il)

Plot	Airfoil	Reynolds #	Ncrit	Max Cl/Cd
✓	naca64208-il	50,000	9	26.6 at α=4.5°
✓	naca64208-il	100,000	9	45.3 at α=3.75°
	naca64208-il	100,000	5	42.8 at α=3.5°
✓	naca64208-il	200,000	9	58.9 at α=3.25°
	naca64208-il	200,000	5	53.3 at α=3°
✓	naca64208-il	500,000	9	75.8 at α=2.75°
	naca64208-il	500,000	5	60.7 at α=2.5°
✓	naca64208-il	1,000,000	9	80.8 at α=2.25°
	naca64208-il	1,000,000	5	70.1 at α=5°

Update plots Reynolds number calculator

Component Weights Available from 1960s Programs

Delta Wing Aircraft	B-58	F-4B	F-102	F-111*
Total Weight	163,000	43,588	31,263	90,453
Wing Group	12,156	4,538	3,000	8,400

Excepting B-58, Wing fraction ~10% of Total Weight.

What drives difference?

Materials, maximum g-levels, technology adapted?...

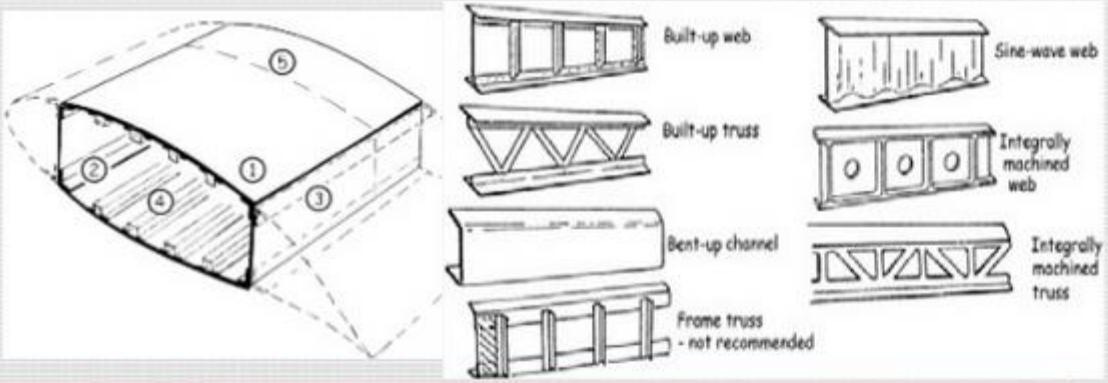
Examining hardware & performance uncertainties,
Required wing weights to meet
Mission requirements & thermal environments
Currently among the least understood or defined.

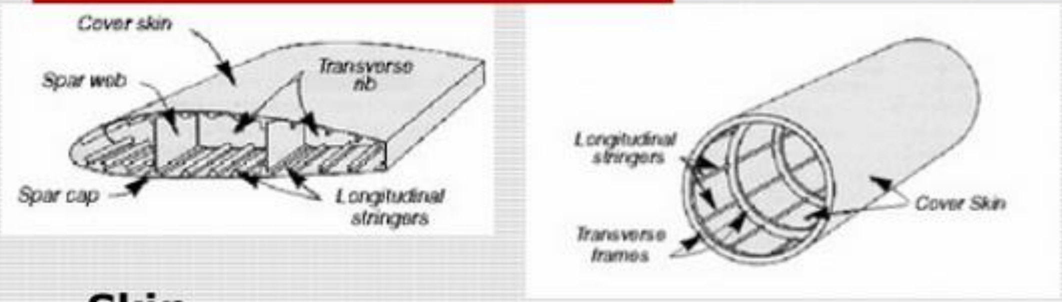
Weight Estimation Process

Level 0 Estimate	Level 1 Estimate	Level 2 Estimate	Level 3 Estimate
Empty Weight			
	Structure		
		Wing	
			Skin
			Spars
			Ribs
			Stringers
		Fuselage	
		Empennage	
		Landing Gear	
	Propulsion		
		Bare Engine	
		Nacelle	
	Systems		
		Electrical Equipment	
		Flight Controls	
		Avionics	
	Interiors/Payload		
		Furnishings	
		Cargo Compartment	
Fuel Weight			
Payload Weight			
Crew Weight			

Spars

1. resist bending and axial loads
2. form the wing box for stable torsion resistance





Skin

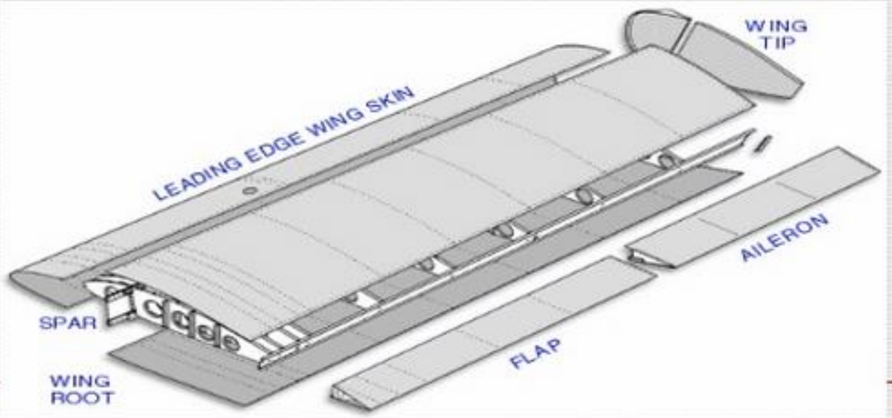
reacts the applied torsion and shear forces
transmits aerodynamic forces to the longitudinal and transverse supporting members

acts with the longitudinal members in resisting the applied bending and axial loads

acts with the transverse members in reacting the hoop, or circumferential, load when the structure is pressurized.

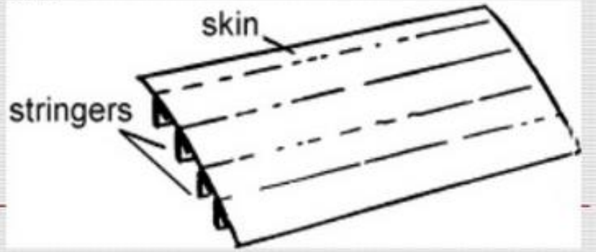
Ribs and Frames

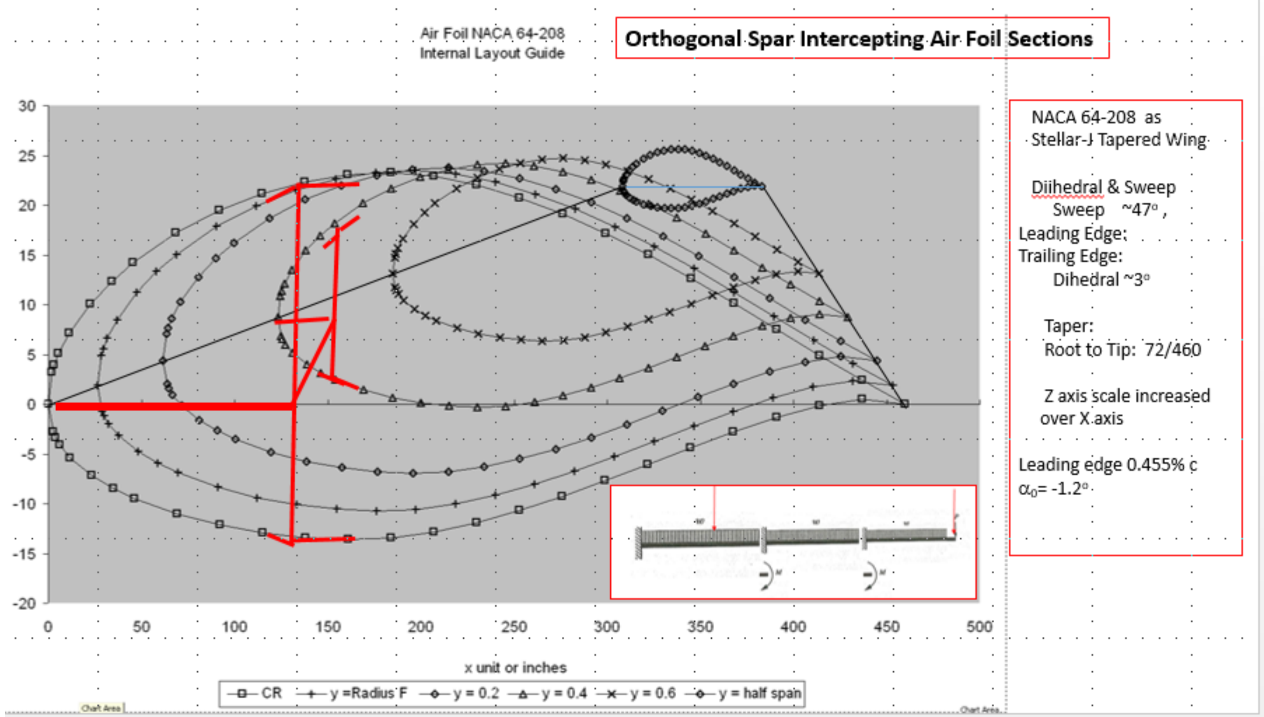
1. Structural integration of the wing and fuselage
2. Keep the wing in its aerodynamic profile



Stiffener or Stringers

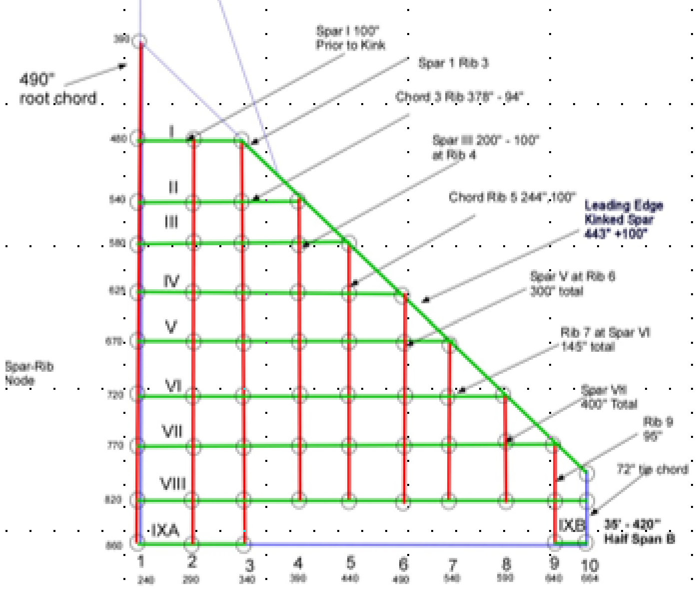
1. resist bending and axial loads along with the skin
2. divide the skin into small panels and thereby increase its buckling and failing stresses
3. act with the skin in resisting axial loads caused by pressurization.

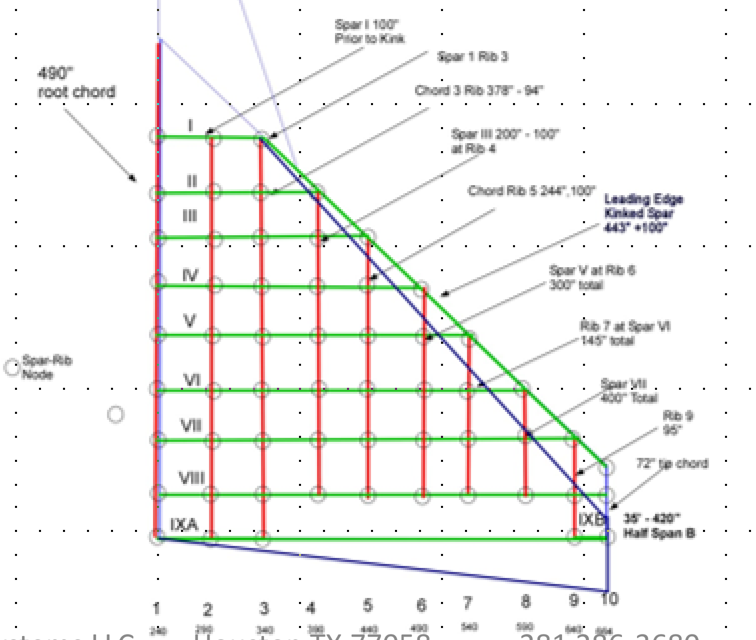


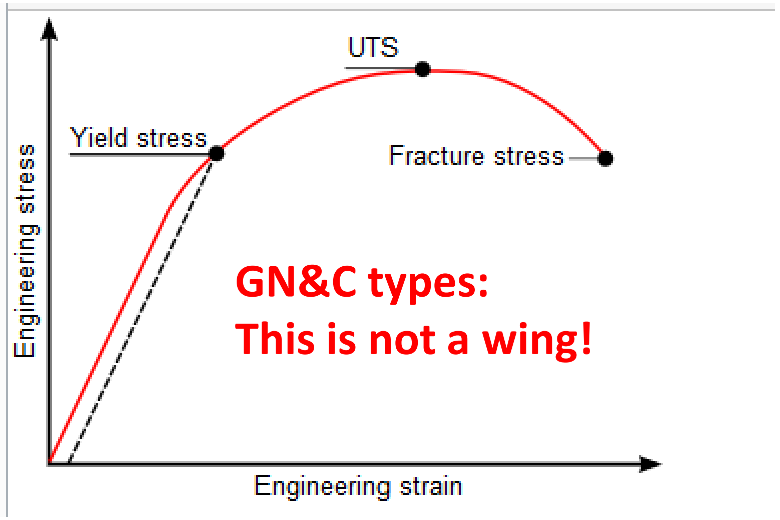


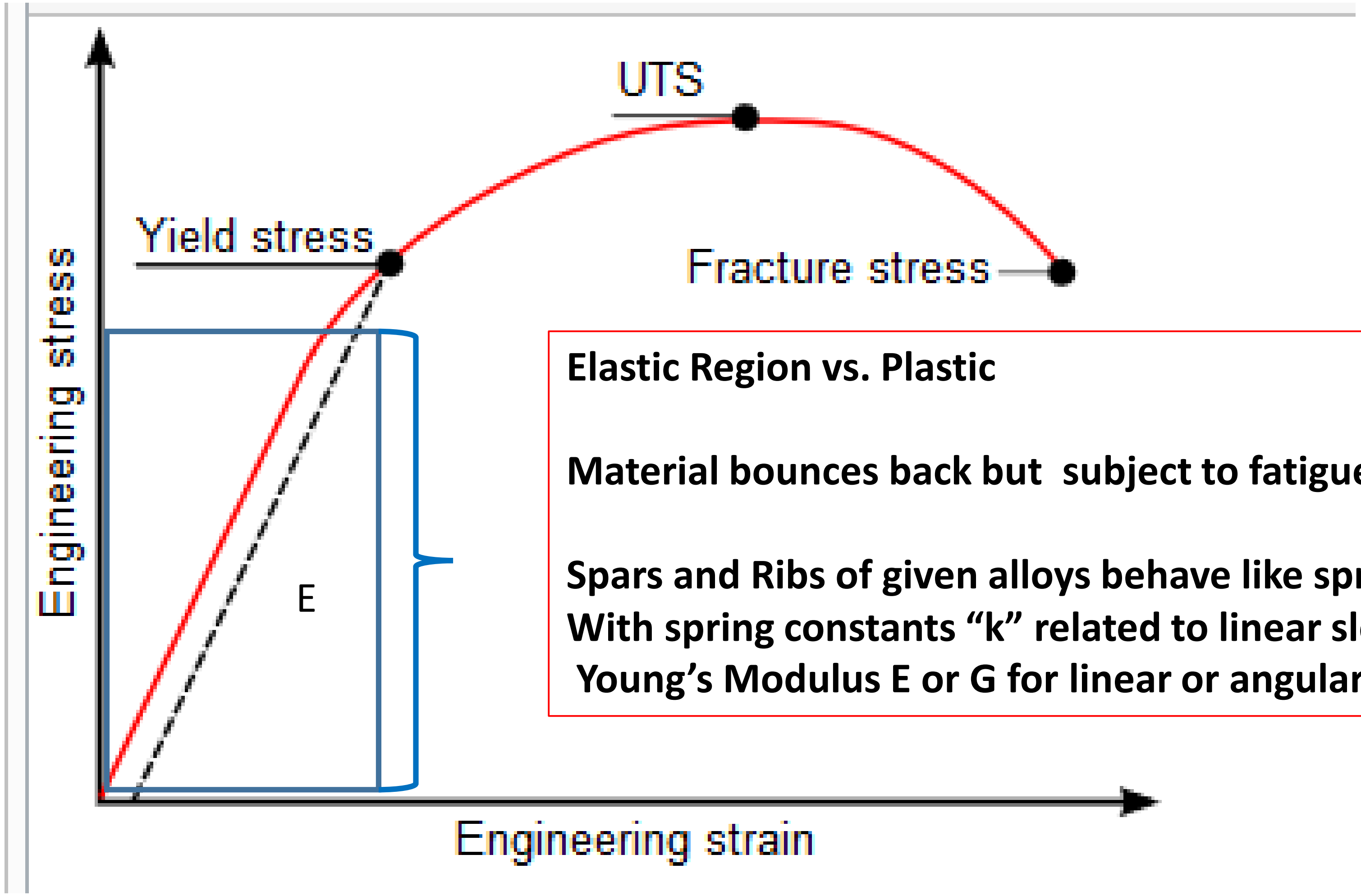
For a swept wing with spars orthogonal
to the fuselage, spars intercept tapered airfoils
At different stations.

Making an estimate of maximum span-wise
heights across torsion boxes bounded
by ribs becomes more complicated,
but within bounds of analysis.









Elastic Region vs. Plastic

Material bounces back but subject to fatigue over n cycles (~10^5)

Spars and Ribs of given alloys behave like springs with
With spring constants "k" related to linear slope $d\sigma/d\varepsilon$ or
Young's Modulus E or G for linear or angular stiffness measures.

This diagram's characteristics vary with alloy – and ambient temperature.

Alloy Characteristics Loaded into "WingMod"   (e.g., See www.matweb.com & www.specialmetals.com)

Computer #	ALLOY	Rho lb/cc	Stress σ Ultimate kpsi	Stress Yield kpsi	Elong Fract	Mod E Mpsi	Poisson Ratio	Shear Strength kpsi	$\Delta\sigma_Y/\Delta$temp Kpsi/° R	$\Delta E/\Delta T$ Mpsi/°R	Temp Range ° R
1	Al-Li 2090 T84	.0936	76.10	68.20	.0500	10.00	.340	46.40 .	?		< 750
2	Al 2219 T6	.1030	55.00	37.00	.0200	11.00	.340	.-	?		< 750
3	Al-Li 8090 T3	.1030	49.30	30.50	.1200	10.60	.340	.-	?		< 750
4	Al-Li 8090 T81	.1030	63.80	49.30	.1300	11.20	.340	.-	?		< 750
5	Ti6Al2Sn 1.5 Zn	.1630	151.00	136.00	.1900	16.70	.310	.-	-.05		460 to1260
6	Ti8Al1Mo 1 V	.1580	171.00	155.00	.1700	17.40	.320	.-	?		
7	Inconel 718	.2960	199.40	160.00	.2500	25.00	.300	.-	-.0340	-0.004	460 to 960
8	Steel Maraging	.2890	150.00	110.00	.1800	27.60	.300	.-	?		

Sample Calculations - Fixed Volumes, Number of Spars and Ribs

# Component Name	Total Volume (in^3)	Alloy Code	Total Mass (lbs)	Alloy Code	Total Mass (lbs)
1 Spars	11298.2	1	1057.5	1	1057.5
2 Ribs	12326.8	1	1153.8	2	1269.7
3 Leading Edge	1425.9	1	133.5	5	232.4
4 Skin	5705.9	1	534.1	1	534.1
Total	**30,757.8**		**2878.8**		**3093.7**

dE/dT & $d\sigma_T/dT$ exist & <0.

Structural Analysis and Influence Coefficients for Delta Wings*

SAMUEL LEVY†
National Bureau of Standards

SUMMARY

A method is presented for determining the stresses and deformations in delta wings of multispar construction having chordwise ribs and thin cover sheets. The spars need not be parallel, and the cover sheets can have large cutouts. The individual spars may be clamped, simply supported, or free at the root. The method is based on the interaction between the bending stiffnesses of the spars and ribs with effective cover sheet and the torsional stiffness of the cover sheet. The method is well suited to the use of high-speed computing machines.

The method will be presented in a form particularly suitable for use with automatic digital computing equipment, since such equipment is finding increased use by aircraft companies. It is felt that the use of such equipment is imperative if the analysis time for highly redundant structures, such as delta wings, is to be kept low enough to allow several alternative configurations to be analyzed in a reasonable length of time.

Levy, Samuel," "Structural Analysis and Influence Coefficients for Delta Wings*, *Journal of the Aeronautical Sciences*, Vol 20, July 1953, No. 3, pp. 449-454.

Premise of "Analysis of Low-Aspect-Ratio Aircraft Structures":

Many types of modern aircraft have **low-aspect ratio (AR or λ)** structural components.

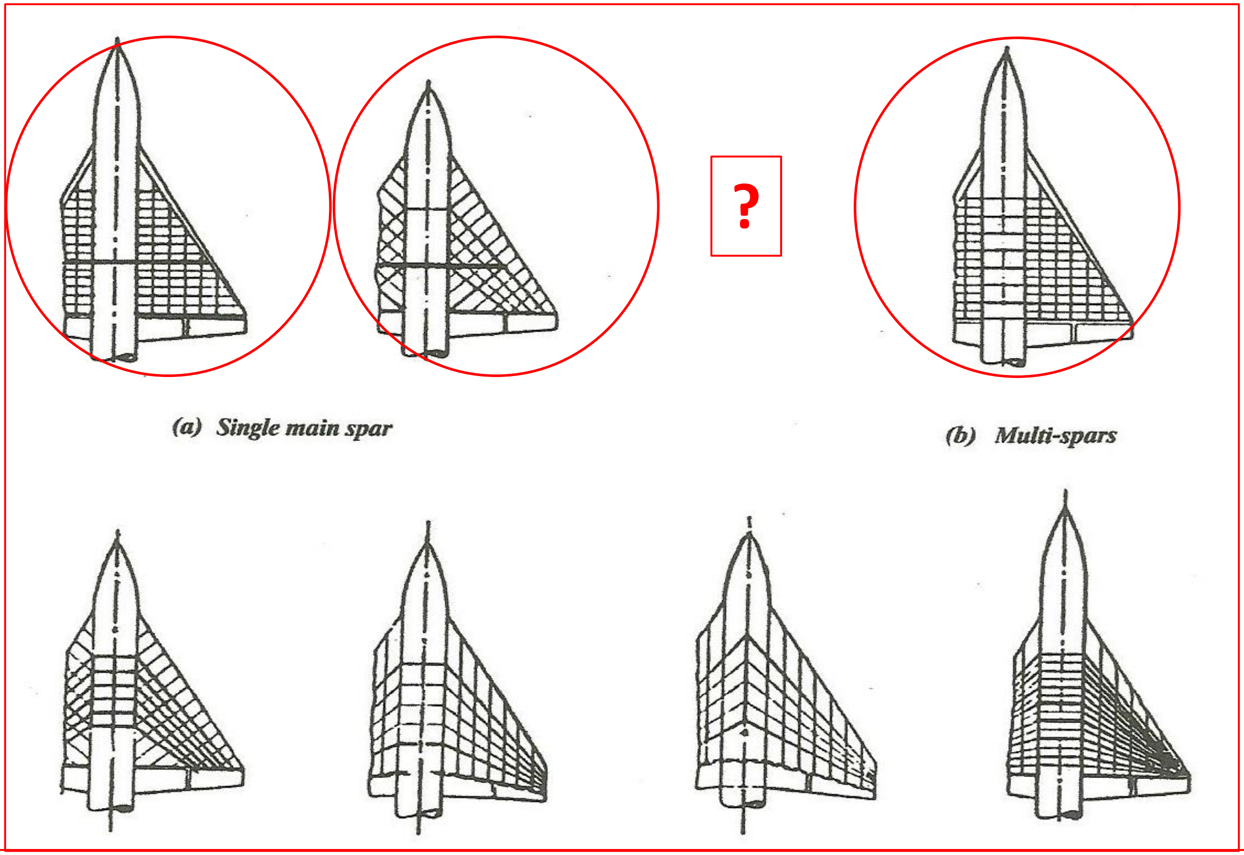
Such structures cannot be treated satisfactorily by elementary beam theory; Consequently, more refined analyses are required.

Analytical procedures development at present (1960), however, restricted by 2 bounds.

1. Analysis of deformations & stresses need sufficient rigor to meet engineering accuracy demands;

2. Computer capabilities place upper limits on the degree of complexity of usable procedures.
(Not necessarily a bad thing!)

An outgrowth of decade earlier work by Sam Levy at NBS referenced above.
(e.g., integration of skin into cross rib and spar cross sectional stiffness)

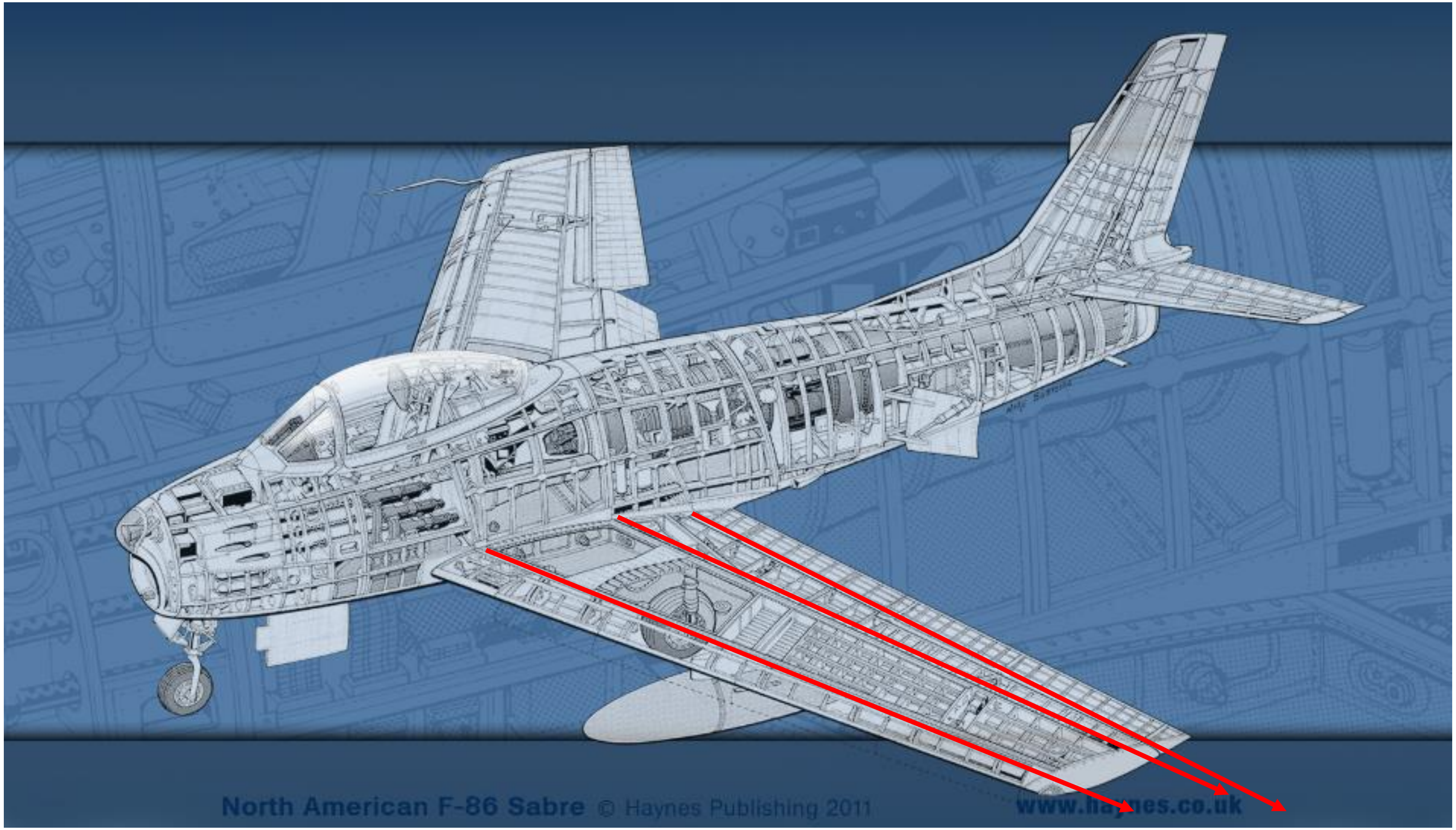


Configuration Trade Candidates: 3 upper right of 7 suggested by Niu to adapt to Stellar-J double delta wing OML Employing varying Rib and Spar Numbers and Lengths.

Considerations: Spar Length **(L_l)** & Thickness in face of Sweep (Λ) and Taper (λ)

Plus point or distributed loads (**P_i**) and cut-outs associated with engines and landing gear.

Constraints: Weight budgets, Airfoil Dimensions, Material Strengths **(E_l, I_l, σ_{Yl})** in face of Aero-thermal, static and dynamic environments of flight.

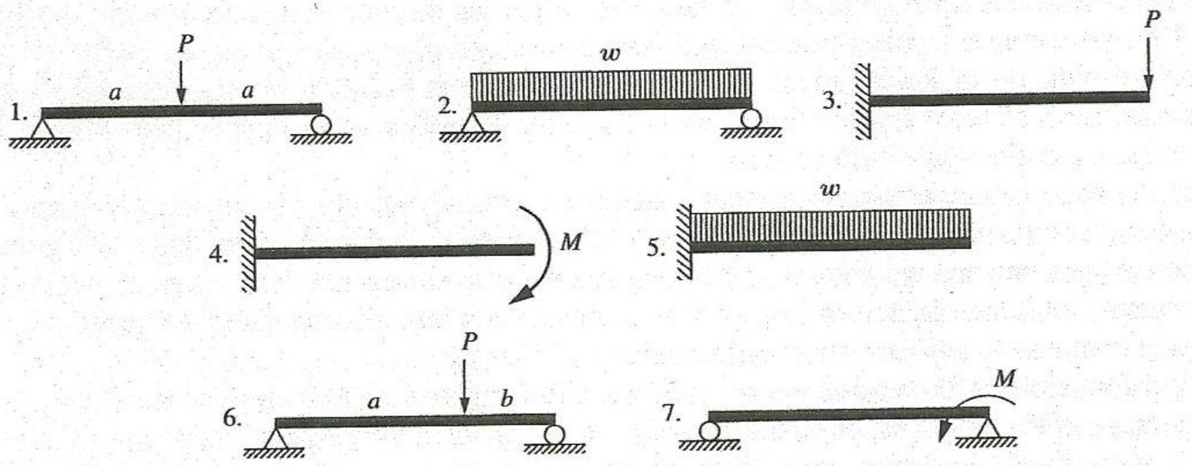


Early 1950s
Technology
F-86 Structural
Layout
Swept wings
With 2 or 3 Spars
Ribs Perpendicular
To Sweep

Argument against “Swept Spars”:
Deflection for loads indicated
Grows to 3rd or 4th Power
of beam length.

Nonetheless, swept spars
Can benefit with bases near
Wide portions of air foil.

	Max Shear	Max Moment	Max Deflection	Max Beam Slope
1	$P/2$	$PL/4$	$PL^3/48EI$	$PL^2/16EI$
2	$wL/2$	$wL^2/8$	$5wL^4/384EI$	$wL^3/24EI$
3	P	PL	$PL^3/3EI$	$PL^2/2EI$
4	0	M	$ML^2/2EI$	ML/EI
5	wL	$wL^2/2$	$wL^4/8EI$	$wL^3/6EI$
6	$\frac{Pa}{L}$	$\frac{Pab}{L}$	$y_{max} = \frac{Pb(L^2-b^2)^{3/2}}{9\sqrt{3}LEI}$ at $x = \sqrt{\frac{L^2-b^2}{3}}$	$\theta_{left} = -\frac{Pb(L^2-b^2)}{6LEI}$
			$y_{center} = \frac{Pb(3L^2-4b^2)}{48EI}$	$\theta_{right} = \frac{Pa(L^2-a^2)}{6LEI}$
7	$\frac{M}{L}$	M	$y_{max} = \frac{\sqrt{3}ML^2}{27EI}$ at $x = \frac{L}{\sqrt{3}}$	$\theta_{left} = -\frac{ML}{6EI}$
			$y_{center} = \frac{ML^2}{16EI}$	$\theta_{right} = \frac{ML}{3EI}$



Analysis of Low-Aspect-Ratio Aircraft Structures†

CHARLES H. SAMSON, JR.,* AND HEINRICH W. BERGMANN
Convair, A Division of General Dynamics Corporation

Journal of the Aero Sciences
September 1960

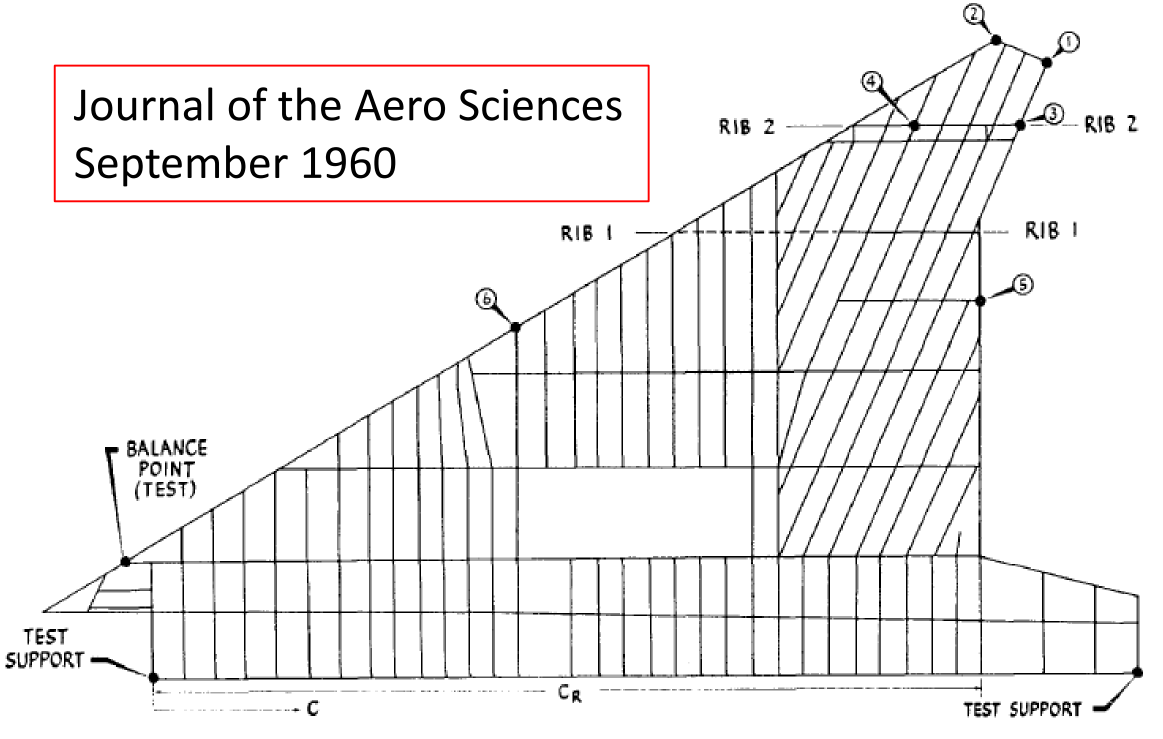


FIG. 25. B-58 $^3/_8$-scale model (reference 27).

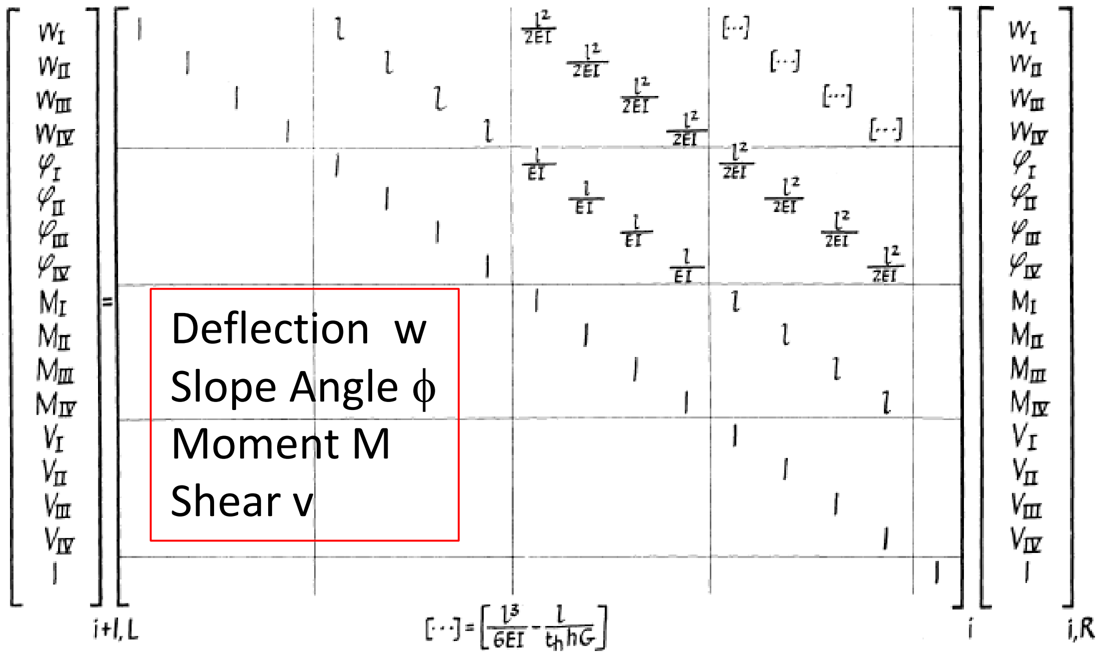
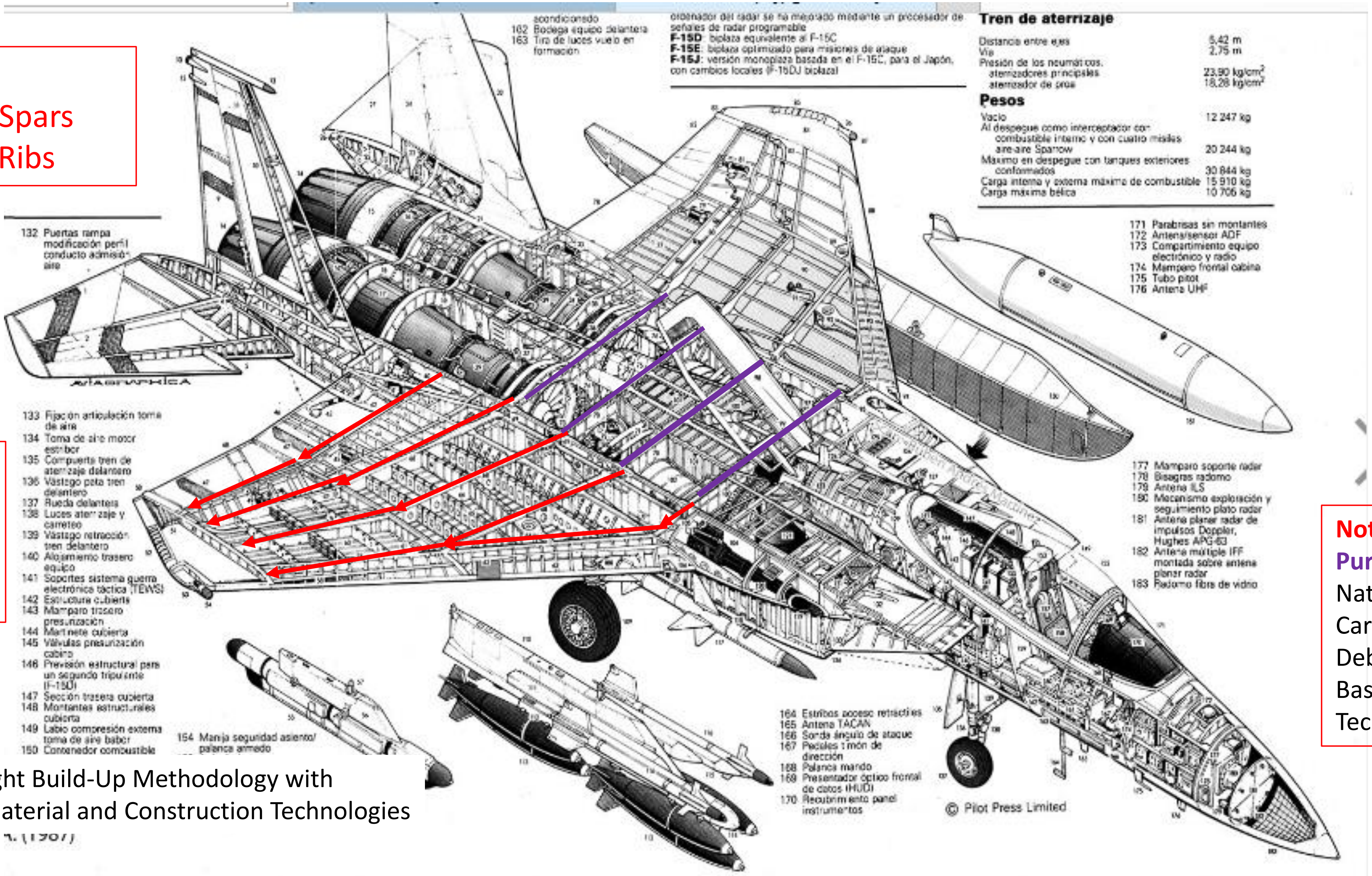


FIG. 14. Typical field matrix.

F-15
Five or Less Spars
Six (Visible) Ribs



Empennage
Structures
Simpler
2 or 3 Spars

Note: Despite **Purple sections**, Nature of Carry Through Debatable Based on Tech Reports.

Aircraft **Wing** Weight Build-Up Methodology with Modification for Material and Construction Technologies

$$
\begin{bmatrix} z_I \\ \phi_I \\ M_I \\ v_I \\ z_{II} \\ \phi_{II} \\ M_{II} \\ v_{II} \\ z_{III} \\ \phi_{III} \\ M_{III} \\ v_{III} \\ z_{IV} \\ \phi_{IV} \\ M_{IV} \\ v_{IV} \end{bmatrix}
=
\begin{bmatrix}
\begin{bmatrix} 1 & L_I & L_i^2/2E_I\, I_I & (L_i^3/(6E_I\, I_I - L_i/t_h\, h\, G_i)] \\ 0 & 1 & L_I/E_I I_I & L_i^2/2\, E_I\, I_I \\ 0 & 0 & 1 & L_i \\ 0 & 0 & 0 & 1 \end{bmatrix} & 0 & 0 & 0 \\
0 & \begin{bmatrix} 1 & L_{II} & L_{iI}^2/2E_{II}\, I_{II} & (L_{iI}^3/(6E_{II}\, I_{IL} - L_i/t_h\, h\, G_{iI})] \\ 0 & 1 & L_{II}/E_I I_I & L_{iI}^2/2\, E_{II}\, I_{II} \\ 0 & 0 & 1 & L_{iI} \\ 0 & 0 & 0 & 1 \end{bmatrix} & 0 & 0 \\
0 & 0 & \begin{bmatrix} 1 & L_{III} & L_{iII}^2/2E_{III}\, I_{III} & (l_{iII}^3/(6E_{III}\, I_{III} - L_{iII}/t_h\, h\, G_i)\} \\ 0 & 1 & L_{III}/E_{III} I_{III} & L_{iII}^2/2\, E_{III}\, I_{III} \\ 0 & 0 & 1 & L_{iII} \\ 0 & 0 & 0 & 1 \end{bmatrix} & 0 \\
0 & 0 & 0 & \begin{bmatrix} 1 & L_{IV} & L_{iV}^2/2E_{IV}\, I_{IV} & [L_{iV}^3/(6E_{IV}\, I_{IV} - L_{iV}/t_h\, h\, G_i)] \\ 0 & 1 & L_{IV}/E_{IV} I_{IV} & L_{iV}^2/2\, E_{IV}\, I_{IV} \\ 0 & 0 & 1 & L_{IV} \\ 0 & 0 & 0 & 1 \end{bmatrix}
\end{bmatrix}
\begin{bmatrix} z_I \\ \phi_I \\ M_I \\ v_I \\ z_{II} \\ \phi_{II} \\ M_{II} \\ v_{II} \\ z_{III} \\ \phi_{III} \\ M_{III} \\ v_{III} \\ z_{IV} \\ \phi_{IV} \\ M_{IV} \\ v_{IV} \end{bmatrix}
$$

Spar “I” Properties

Spar “II” Properties

Spar “III” Properties

Spar “IV” Properties

Conditions with rib “i+1” intersection.

E, I and L

Conditions with rib “i” intersection.

Row Hierarchies Matter! Response to Sparse Matrices

Block Matrices behave like individual matrix elements

Matrix **A** $= \begin{bmatrix} a & b \\ c & d \end{bmatrix}$ Determinant Δ of A = ad-bc

Matrix **A'** $= \begin{bmatrix} A & B \\ C & D \end{bmatrix}$ where A $= \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$ B= $\begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$, et cetera.

Δ **A'** = Det [**AD**-BC]

Matrix **A"** = $\begin{bmatrix} \mathbf{A} & \mathbf{B} & \mathbf{C} \\ \mathbf{D} & \mathbf{E} & \mathbf{F} \\ \mathbf{G} & \mathbf{H} & \mathbf{I}^* \end{bmatrix}$ Δ **A" =| A(EI-HF) –B (DI-GF)+C(DH-GE)|**

Off Diagonal Elements Block Elements either 0 or sparsely populated.
* I not necessarily identity matrix.

If C = G =0,

Det A" = **|A(EI-HF) –BDI|**

If C=G=H=F,

Det **A"** = **|AEI|**

$A(EI-HF)-B(DI-GF)+C(DH-GE)=AEI-BDI$

$$
\begin{array}{cccccccccccc}
R_{AI} & R_{BI} & M_{AI} & z_I(L_I) & R_{AII} & R_{BII} & M_{AII} & z_{II}(L_{II}) & R_{AIII} & R_{BIII} & M_{AIII} & z_{III}(L_{III})
\end{array}
$$

$$
\left[\begin{array}{cccc:cccc:cccc}
(1) & (1)\ \mathbf{A} & (0) & (0) & & \mathbf{B} & & & & \mathbf{C} & & \\
(0) & (1) & (0) & (k_{I-II}) & & & & (-k_{I-II}) & & & & \\
(0) & (L_I) & (1) & (0) & & & & & & & & \\
(L_I^3/6) & (0) & (L_I^2/2) & (-E_I I_I) & & & & & & & & \\
\hdashline
 & & & & (1) & (1) & (0) & (0) & & & & \\
 & \mathbf{D} & & (-k_{I-II}) & (0) & (0) & \mathbf{E}\ (0) & (k_{I-II}\ -k_{II-III}) & & \mathbf{F} & & (k_{II-III}) \\
 & & & & (0) & (L_{II}) & (1) & (0) & & & & \\
 & & & & (L_{II}^3/6) & (0) & (L_{II}^2/2) & (-E_{II} I_{II}) & & & & \\
\hdashline
 & & & & & & & & (1) & (1) & (0) & (0) \\
 & \mathbf{G} & & & & \mathbf{H} & & & (0) & (1) & (0)\ \mathbf{I} & (k_{II-III}) \\
 & & & & & & & & (0) & (L_{III}) & (1) & (0) \\
 & & & & & & & & (L_{III}^3/6) & (0) & (L_{III}^2/2) & (-E_{III} I_{III})
\end{array}\right]
\left[\begin{array}{c}
R_{AI} \\ R_{BI} \\ M_{AI} \\ Z_I(L_I) \\ R_{AII} \\ R_{BII} \\ M_{AII} \\ Z_{II}(L_{II}) \\ R_{AIII} \\ R_{BIII} \\ M_{AIII} \\ Z_{III}(L_{III})
\end{array}\right]
+
\left[\begin{array}{c}
P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \\ P_9 \\ P_{10} \\ P_{11} \\ P_{12}
\end{array}\right]
=
\left[\begin{array}{c}
0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{array}\right]
$$

P_1, P_5, P_9: Functions of point loads P_I<a_I>, unform loads $w_0 y$<a_I>, ramps cy <a_I> etc,

P_2, P_6, P_{10}: = 0 Loads associated with spring/rib reactive forces at points P_I, at end of L_I, L_{II}, L_{III}...

P_3, P_7, P_{11}: Integration s of P_1, P_5, P_9 to reflect moments at base point (A) for each spar, countered by reactive forces R_A

$P_4; P_8, P_{12}$: Integrations from moment rellation, z deflections at end points, $Z_I(L_I), Z_{II}(L_{II}), Z_{III}(L_{III})$

Spars: Roman numerals I, II, III...
Ribs: i, i+1, i+2...

Spring Constant k_{I-II} i
ith Rib stiffness between Spar I & II

R_{AI}	R_{BI}	M_{AI}	$z_I(L_I)$	R_{AII}	R_{BII}	M_{AII}	$z_{II}(L_{II})$	R_{AIII}	R_{BIII}	M_{AIII}	$z_{III}(L_{III})$
(1)	(1)	(0)	P_1								
(0)	(1) A	(0)	$P_2=0$	B			$(-k_{I-II})$	C			
(0)	$(L_I)($	1)	P_3								
$(L_I^3/6)$	(0)	$(L_I^2/2)$	P_4								
			P_5	(1)	(1)	(0)	(0)				
D			$P_6=0$	(0)	(0) E	(0)	$(k_{I-II}\ -k_{II-III})$	F			(k_{II-III})
			P_7	(0)	(L_{II})	(1)	(0)				
			P_8	$(L_{II}^3/6)$	(0)	$(L_{II}^2/2)$	$(-E_{II}I_{II})$				
			P_9					(1)	(1)	(0)	(0)
G			$P_{10}=0$	H				(0)	(1)	(0) I	(k_{II-III})
			P_{11}					(0)	(L_{III})	(1)	(0)
			P_{12}					$(L_{III}^3/6)$	(0)	$(L_{III}^2/2)$	$(-E_{III}I_{III})$

$$A(EI-HF)-B(DI-GF)+C(DH-GE)$$

$$=AEI-BDI$$

$/ \text{ Det TM} = z_I(L_I)$

P_1, P_5, P_9: Functions of point loads P_{Ii}<a_i>, unform loads w_0y<a_i>, ramps cy <a_i> etc,

P_2, P_6, P_{10}: $=0$ Loads associated with spring/rib reactive forces at points P_I, at end of L_I, L_{II}, L_{III}..

P_3, P_7, P_{11}: Integration s of P_1, P_5, P_9 to reflect moments at base point (A) for each spar, countered by reactive forces R_A

P_4: P_8, P_{12}: Integrations from moment rellation, z deflections at end points, $Z_I(L_I)$, $Z_{II}(L_{II})$, $Z_{III}(L_{III})$

Spars: Roman numerals I, II, III...
Ribs: i, i+1, i+2...

Spring Constant k_{I-II} i
ith Rib stiffness between Spar I & II

$$\Delta = E_I I_I \; E_{II} I_{II} \,[\, 1 + k_{I\text{-}II}(L_{II}^3/6 + L_{II}^2 L_I /2)] - k_{I\text{-}II} E_{II} I_{II} \,(5/6 L_{II}^3 + L_{II} L_I^2/2)$$

Deflection z, Moment at A M_A, Reactive Forces at R_A and R_B

$$z_I(L_I) = \{ -E_{II} I_{II} \,[\, P_4(1- L_{II}^2 P_3) + (1/12-2/3P_3)\, P_1 L_{II}^5 \,] + \ldots$$

$$+ k_{I\text{-}II} \,[\, L_I \,(1 - P_8 L_{II} [1+(1+P_3/2)L_{II} +L_{II}^3/6\, P_1+1/6(1-P_3)L_{II}^4 P_4 +L_{II}^5\, P_1P_3/12] \ldots$$

$$-P_8 \,(P_4/3\, L_{II}^2 - 1/6\, (P_1P_4 +P_3 +P_3P_4L_{II}^4 - P_1P_4L_{II}^7)\}/ \Delta$$

$$z_{II}(L_{II}) = \{ -E_I I_I \,[\, P_8- P_5- P_7 L_{II}^2) -P_4 L_I^3 /2 -P_4 L_{II}^2 /2 \}/ \Delta$$

$$M_{AI} = (L_I^2 +L_{II}^2)P_4\{ E_{II} I_{II} [1+L_{II}^3P_3(P_1-1)$$

$$-k_{I\text{-}II}[1- L_{II}^3/6(L_I + L_{II})\, P_1-2P_3 +P1P_3P_8L_X^2/2]\}/ \Delta$$

Spar Lengths

$L_I = (y_{I1}-y_{I0})/\cos\Lambda_I$

$L_{II} = (y_{II1}-y_{II0})/\cos\Lambda_{II}$

$$M_{AII} = E_I I_I E_{II} I_{II} P_7/ \Delta$$

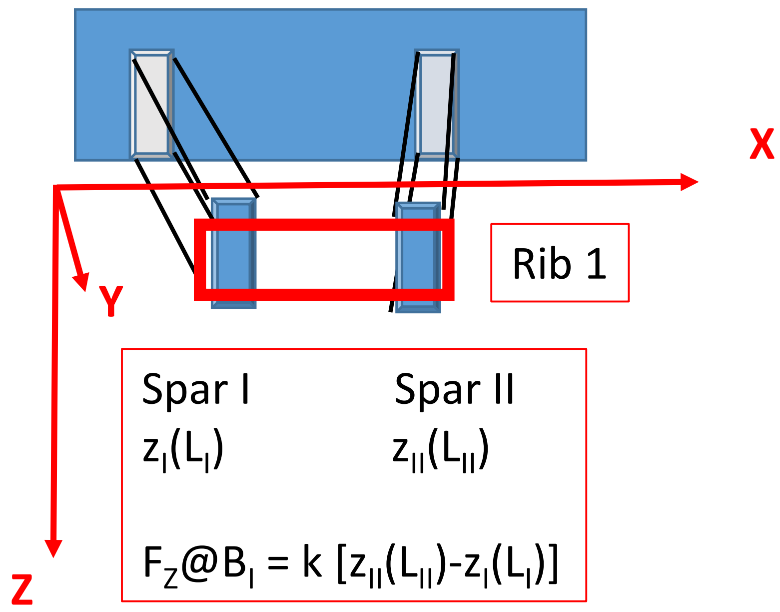
$$R_{AI} = E_I I_I E_{II} I_{II} \;[P_1 + k_{I\text{-}II} (P_1P_8+ P_8)] \quad / \Delta$$

$$R_{BI} = - k_{I\text{-}II} E_I I_I E_{II} I_{II} / \Delta$$

"Numerical" or "Analytical"?
2 Cantilever Beams connected by Spring

Analogous to the first torque box of
2 Spars connected by 1 rib at their ends.

PRELIMINARY & PROVISIONAL
BUT ILLUSTRATIVE



Spar I	Spar II
$z_I(L_I)$	$z_{II}(L_{II})$

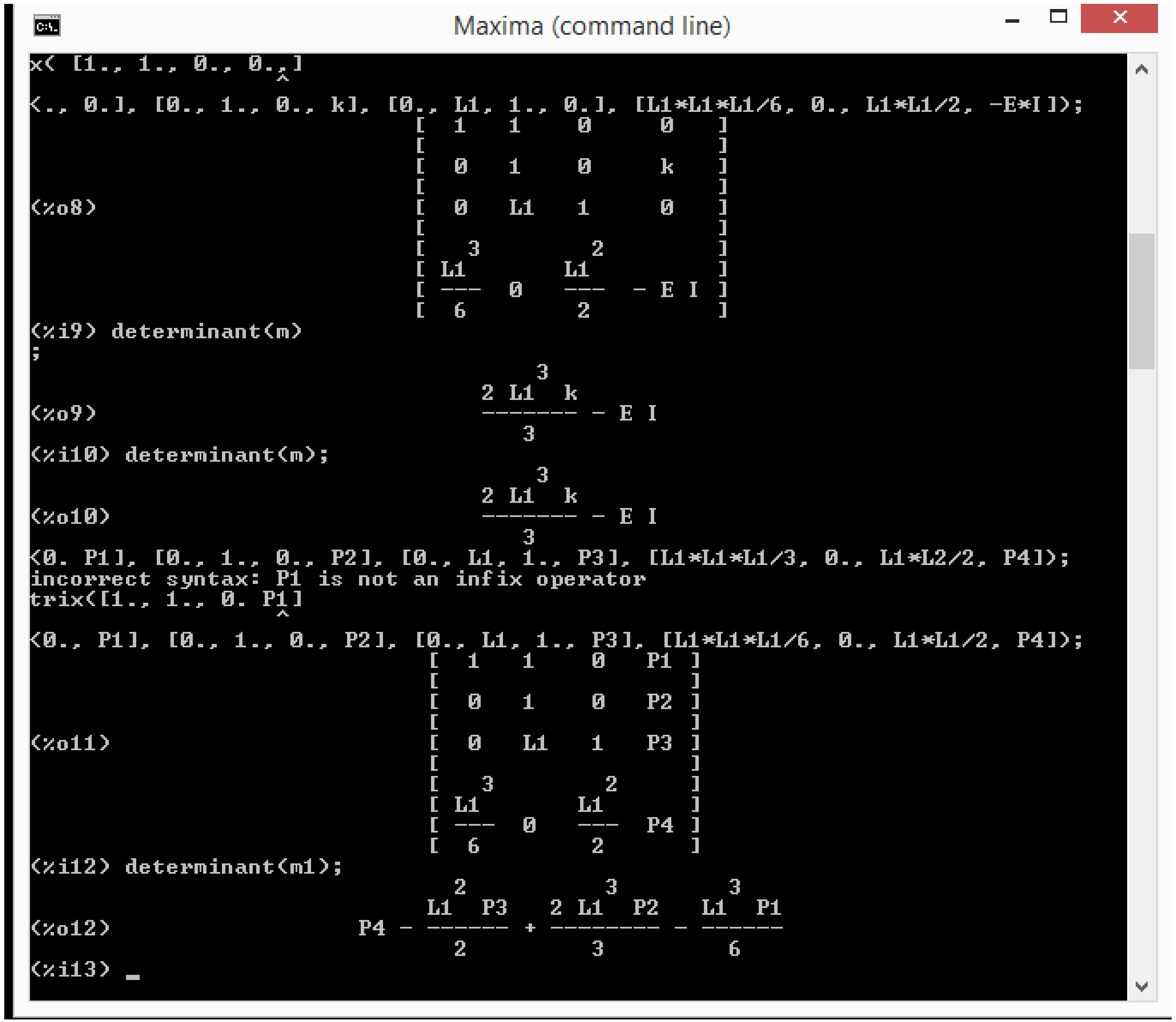
$F_Z@B_I = k\,[z_{II}(L_{II})-z_I(L_I)]$

What about 3 Spars & 2 Ribs Analytical solution?

$$A(EI-HF)-B(DI-GF)+C(DH-GE)=AEI-BDI$$

$$
\begin{array}{cccc|cccc|cccc}
R_{AI} & R_{BI} & M_{AI} & z_I(L_I) & R_{AII} & R_{BII} & M_{AII} & z_{II}(L_{II}) & R_{AIII} & R_{BIII} & M_{AIII} & z_{III}(L_{III})
\end{array}
$$

$$
\left|\begin{array}{cccc|cccc|cccc}
(1) & (1)\ \mathbf{A} & (0) & (0) & & \mathbf{B} & & & & \mathbf{C} & & \\
(0) & (1) & (0) & (k_{I-II}) & & & & (-k_{I-II}) & & & & \\
(0) & (L_I)(& 1) & (0) & & & & & & & & \\
(L_I^3/6) & (0) & (L_I^2/2) & (-E_I I_I) & & & & & & & & \\
\hline
(1) & (1) & (0) & (0) & & & & & & & & \\
 & \mathbf{D} & & (-k_{I-II}) & (0) & (0)\ \mathbf{E} & (0) & (k_{I-II}\ -k_{II-III}) & & \mathbf{F} & & (k_{II-III}) \\
 & & & & (0) & (L_{II}) & (1) & (0) & & & & \\
 & & & & (L_{II}^3/6) & (0) & (L_{II}^2/2) & (-E_{II} I_{II}) & & & & \\
\hline
 & & & & & & & & (1) & (1) & (0) & (0) \\
 & \mathbf{G} & & & & \mathbf{H} & & & (0) & (1) & (0)\ \mathbf{I} & (k_{II-III}) \\
 & & & & & & & & (0) & (L_{III}) & (1) & (0) \\
 & & & & & & & & (L_{III}^3/6) & (0) & (L_{III}^2/2) & (-E_{III} I_{III})
\end{array}\right|
\left|\begin{array}{c}
R_{AI} \\ R_{BI} \\ M_{AI} \\ Z_I(L_I) \\ R_{AII} \\ R_{BII} \\ M_{AII} \\ Z_{II}(L_{II}) \\ R_{AIIII} \\ R_{BIII} \\ M_{AIII} \\ Z_{III}(L_{III})
\end{array}\right|
+
\left|\begin{array}{c}
P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \\ P_9 \\ P_{10} \\ P_{11} \\ P_{12}
\end{array}\right|
=
\left|\begin{array}{c}
0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{array}\right|
$$



Caveat:

Even with Sparse Block Matrices
N grows large for series & factors.

Don't try this at home
Without MathCad or similar tool.
or
Without annual license $.

Note: Macsyma now available
Via Source Forge…

What about the deflection of segments as a function of (T) Element Temperature?

$$d\Delta /dT = d/dT\{ \ E_I I_I \ E_{II} I_{II} [1 + k_{I\text{-}II}(L_{II}^3/6 + L_{II}^2 L_I /2)] - k_{I\text{-}II} E_{II} I_{II} (5/6 L_{II}^3 + L_{II} L_I^2/2) \}$$

$$=(d\Delta/dEI)(dE_I/dt)+ d\Delta/dE_{II} \, dE_{II}/dt$$

$$dz_I(L_I)/dT = d/dT\{ \{ -E_{II} I_{II} [P_4(1- L_{II}^2 P_3) + (1/2-2/3 P_3) P_1 L_{II}^5] + \ldots + k_{I\text{-}II} [L_I (1- P_8 L_{III}^2 \ [\ldots. \}/ \Delta\}$$

$$=(dz_I(L_I)/dE_I)(dE_I/dT)+ (dz_I(L_I)/dE_{II}) (dE_{II}/dT)$$

$$dz_{II}(L_{II})dT = d/dT\{ \{ -E_I I_I [P_8- P_5- P_7 L_{II}^2) -P_4 L_I^3 /2 -P_4 L_{II}^2 /2 \}/ \Delta \}$$

$$=(dz_{II}(L_{II})/dE_I)(dE_I/dt)+ dz_{II}(L_{II})/dE_{II} \, dE_{II}/dt$$

Spring or Rib Properties?

$d\Delta /dk_{I\text{-}II}$ = ….. $d\Delta/ dk_{II\text{-}III}$ = …

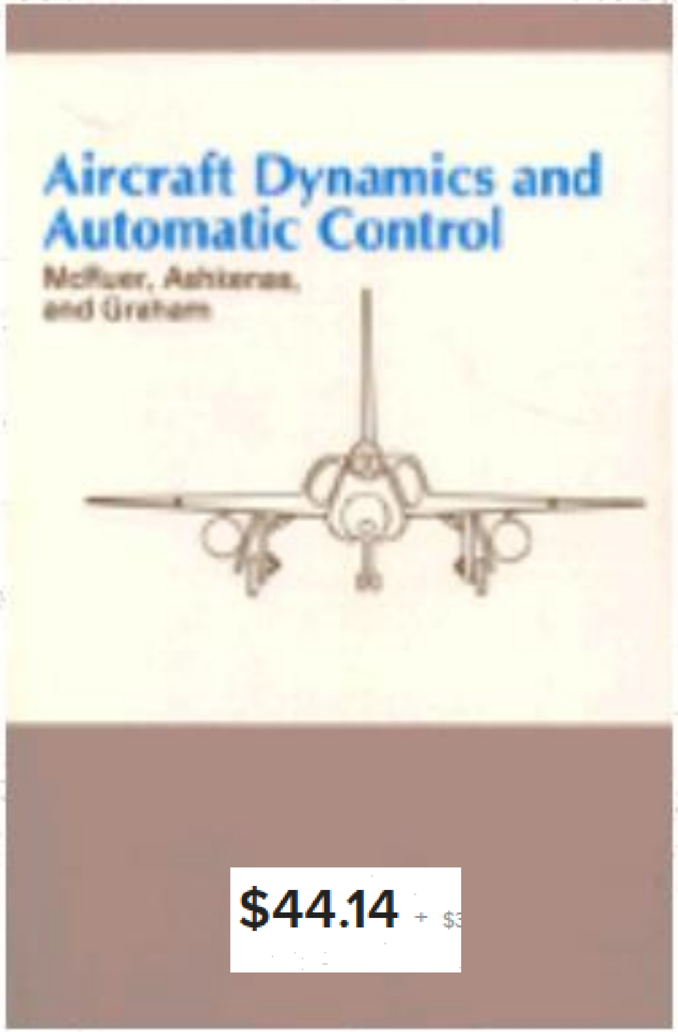
Spar Length or Sweep…

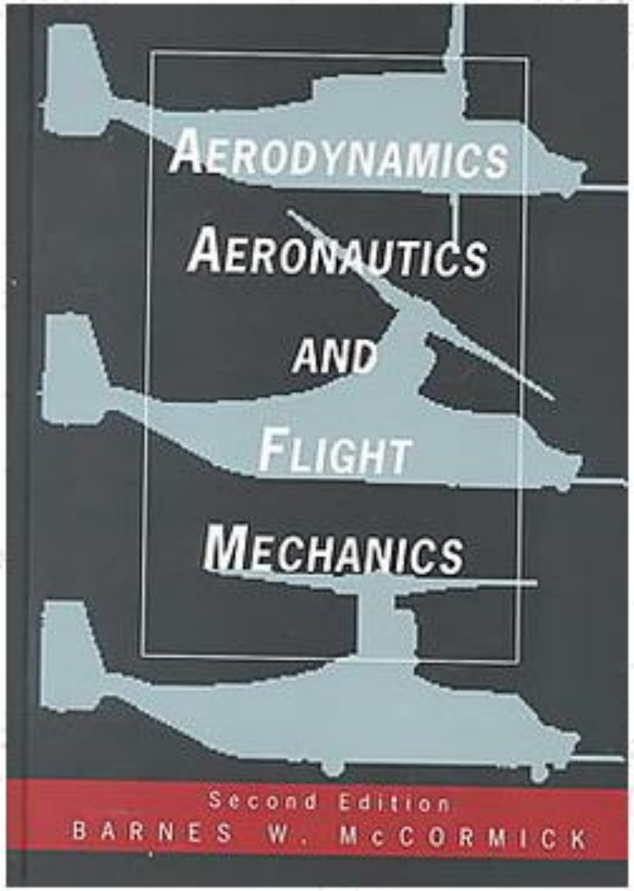
$dz_I(L_I)/d L \ dz_I(L_I)/dT$ …

….Pretty soon we are talking about optimization subject to constraints.

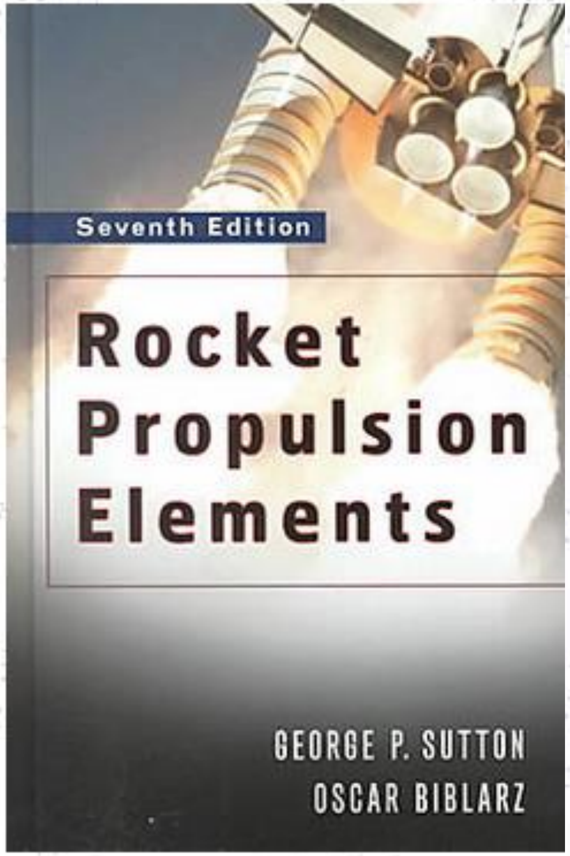
Chain Rule for Derivatives

Some Very Helpful Books at this Design Stage - Plus Used Book Store Price Quotes

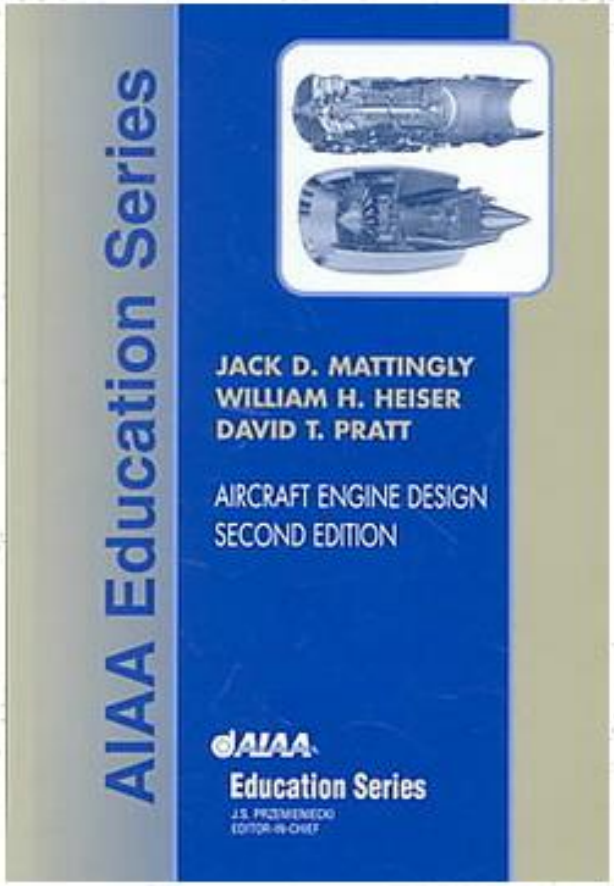




$24.33 + $3.



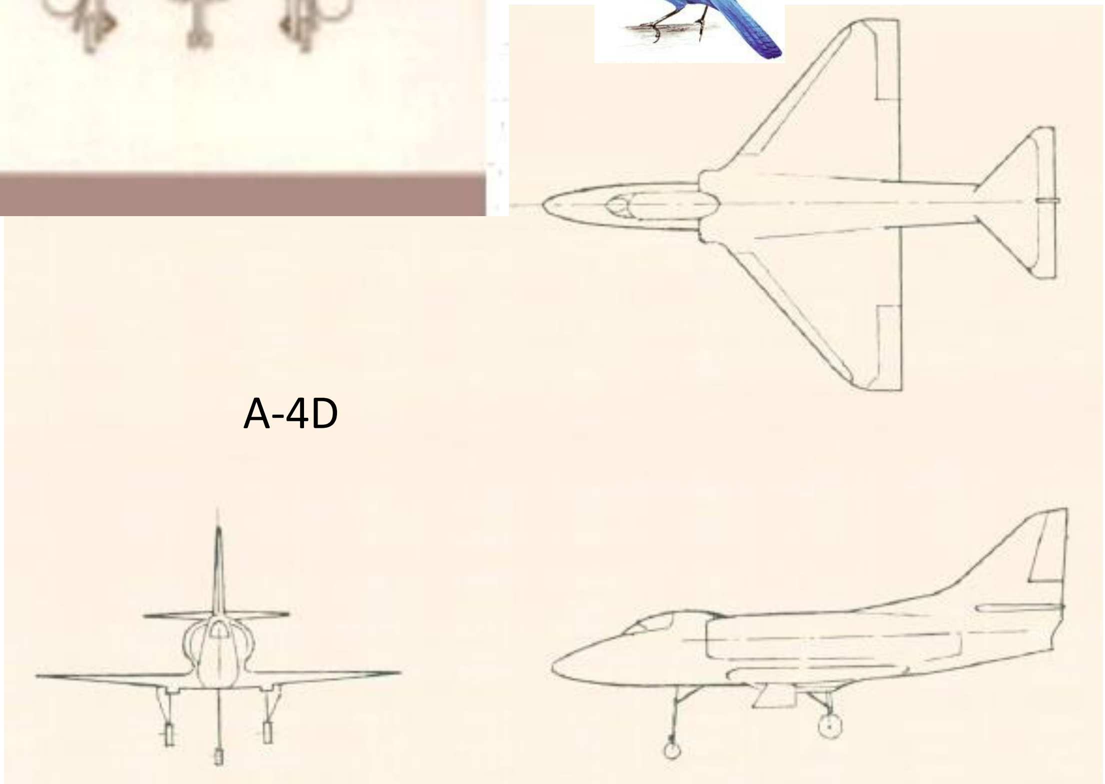
$39.63 + $3.99 est. shipping



$71.41 + $

Appendix A

Listings for Numerous Aircraft



A-4D

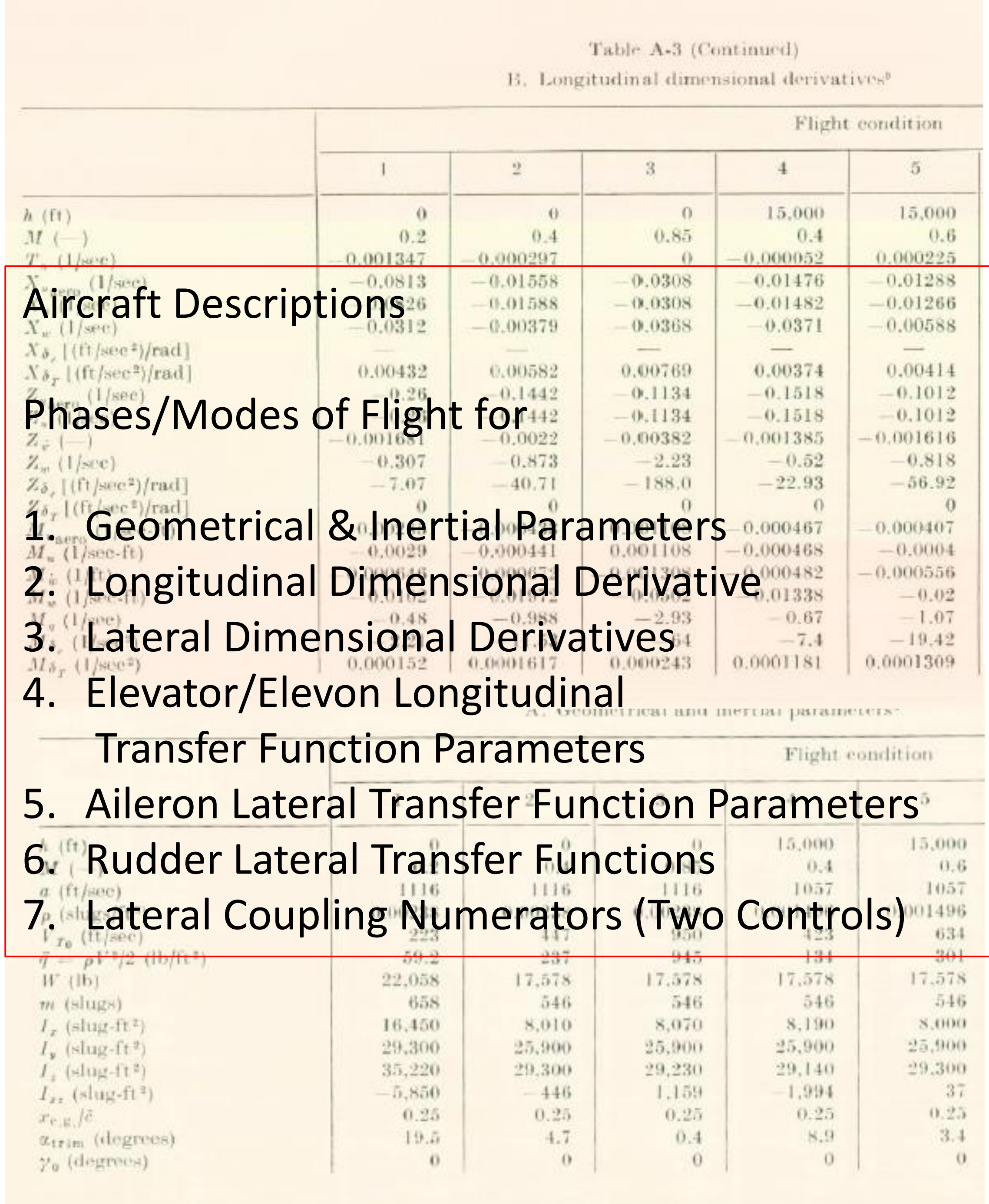


Table A-3 (Continued)

B. Longitudinal dimensional derivatives[b]

	Flight condition 1	2	3	4	5
h (ft)	0	0	0	15,000	15,000
M (—)	0.2	0.4	0.85	0.4	0.6
T_u (1/sec)	−0.001347	−0.000297	0	−0.000052	0.000225
$X_{u_{aero}}$ (1/sec)	−0.0813	−0.01558	−0.0308	−0.01476	−0.01288
[illegible]	[illegible]	−0.01588	−0.0308	−0.01482	−0.01266
X_w (1/sec)	−0.0312	−0.00379	−0.0368	−0.0371	−0.00588
X_{δ_e} [(ft/sec²)/rad]	—	—	—	—	—
X_{δ_T} [(ft/sec²)/rad]	0.00432	0.00582	0.00769	0.00374	0.00414
$Z_{u_{aero}}$ (1/sec)	−0.26	−0.1442	−0.1134	−0.1518	−0.1012
[illegible]	[illegible]	[illegible]	−0.1134	−0.1518	−0.1012
$Z_{\dot{w}}$ (—)	−0.001681	−0.0022	−0.00382	−0.001385	−0.001616
Z_w (1/sec)	−0.307	−0.873	−2.23	−0.52	−0.818
Z_{δ_e} [(ft/sec²)/rad]	−7.07	−40.71	−188.0	−22.93	−56.92
Z_{δ_T} [(ft/sec²)/rad]	0	0	0	0	0
$M_{u_{aero}}$	[illegible]	[illegible]	[illegible]	0.000467	0.000407
M_u (1/sec-ft)	0.0029	−0.000441	0.001108	−0.000468	−0.0004
$M_{\dot{w}}$ (1/ft)	[illegible]	[illegible]	[illegible]	[illegible]	−0.000556
M_w (1/sec-ft)	[illegible]	[illegible]	[illegible]	[illegible]	−0.02
M_q (1/sec)	−0.48	−0.988	−2.93	−0.67	−1.07
M_{δ_e}	[illegible]	[illegible]	[illegible]	−7.4	−19.42
M_{δ_T} (1/sec²)	0.000152	0.0001617	0.000243	0.0001181	0.0001309

A. Geometrical and inertial parameters

	Flight condition 1	2	3	4	5
h (ft)	0	0	0	15,000	15,000
M	[illegible]	[illegible]	[illegible]	0.4	0.6
a (ft/sec)	1116	1116	1116	1057	1057
ρ (slugs/ft³)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V_{T_0} (ft/sec)	223	447	950	423	634
$\bar{q} = \rho V^2/2$ (lb/ft²)	59.2	237	945	134	301
W (lb)	22,058	17,578	17,578	17,578	17,578
m (slugs)	658	546	546	546	546
I_x (slug-ft²)	16,450	8,010	8,070	8,190	8,000
I_y (slug-ft²)	29,300	25,900	25,900	25,900	25,900
I_z (slug-ft²)	35,220	29,300	29,230	29,140	29,300
I_{xz} (slug-ft²)	−5,850	−446	1,159	−1,994	37
$x_{c.g.}/\bar{c}$	0.25	0.25	0.25	0.25	0.25
α_{trim} (degrees)	19.5	4.7	0.4	8.9	3.4
γ_0 (degrees)	0	0	0	0	0

Aircraft Descriptions

Phases/Modes of Flight for

1. Geometrical & Inertial Parameters
2. Longitudinal Dimensional Derivative
3. Lateral Dimensional Derivatives
4. Elevator/Elevon Longitudinal Transfer Function Parameters
5. Aileron Lateral Transfer Function Parameters
6. Rudder Lateral Transfer Functions
7. Lateral Coupling Numerators (Two Controls)

Design Activity
Stellar-J Descriptions

Phases/Modes of Flight for

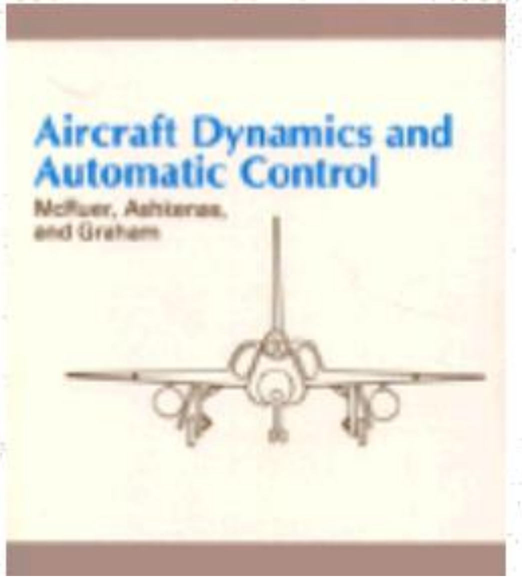
1. Geometrical & Inertial Parameters
2. Longitudinal Dimensional Derivatives
3. Lateral Dimensional Derivatives
4. Elevon Longitudinal Transfer Function Parameters
5. Aileron Lateral Transfer Function Parameters
6. Rudder Lateral Transfer Functions
7. Lateral Coupling Numerators (Two Controls)

BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ
	primary	**units**	units	w/o glove												
	Sref wing	ft2	ft2	1317	1317	1317	1317	1317	1317	1317	1317	1317	1317	1317	1317	1317
	bspan	ft2	ft2	70	70	70	70	70	70	70	70	70	70	70	70	70
	Cr chord	inches	inches	490	490	490	490	490	490	490	490	490	490	490	490	490
	Ct chord	inches	inches	72	72	72	72	72	72	72	72	72	72	72	72	72
	taper			0.1469	0.1469	0.1469	0.146939	0.1469	0.146939	0.14694	0.1469	0.146939	0.14694	0.14694	0.14694	0.1469
	sweep Le	deg	deg	45	45	45	45	45	45	45	45	45	45	45	45	45
	sweep Le	deg	deg	0	0	0	0	0	0	0	0	0	0	0	0	0
	C bar m		inches	332.82	332.82	332.82	332.8161	332.82	332.8161	332.816	332.82	332.8161	332.816	332.816	332.816	332.82
	g			32.174	32.174	32.174	32.174	32.174	32.174	32.174	32.174	32.174	32.174	32.174	32.174	32.174
	pi			3.1416	3.1416	3.1416	3.141593	3.1416	3.141593	3.14159	3.1416	3.141593	3.14159	3.14159	3.14159	3.1416
	Secondary															
	horizontal tail		ft2	0												
	elevon		ft2													
	elevator		dt2													
	aileron		dt2													
	rudder		ft2													
	speed brake		ft2													
	body flap		ft2													
Aircraft	**Stellar-J 35**		name	Nominal flight												
Parameters																
number	name		units	0	1	2	3	4	5	6	7	8	9	10	11	12
0	S	ref area	ft2													
0	b	span	ft													
0	c	chord me	ft													
0	gamma0	fpa	deg													
1	h	alt	ft		0	10000	25000	35000	45000	60000	100000	70000	45000	25000	5000	0
2	Mach				0.3	0.7	0.8	0.85	0.9	1.2	3.5	2.5	1.2	0.9	0.5	0.2
3	a	sound	fps		1116.7	1077.4	1016	973.14	968.08	968.18		968.18	973.14	1016	1097.1	1116.7
4	rho	density	slug/ft3		0.0024	0.0018	1.07E-03	0.0007	4.62E-04	2.26E-04		1.40E-04	4.62E-04	1.07E-03	2.05E-03	0.0024
5	Vt0	tanveloc	fps		335.01	754.18	812.8	827.17	871.272	1161.82	0	2420.45	1167.77	914.4	548.55	223.34
6	q	dynamic	lb/ft2		133.44	499.28	352.2223	252.47	175.458	152.266	0	409.8954	315.195	445.781	308.234	59.308

Under Construction

Engine Trades | Standard Atmos | Quartic Roots | R ...

Many aerospace publications similar to McRuer, Ashkenas and Graham's **Aircraft Dynamics &Automatic Control,** but this is a particularly thorough treatment of linear theory with an abundance of aircraft illustrations.



Search on line indicates that NASA Ames and other agencies in the 60s-70s' examined 50-100 aircraft in detail. In addition to control – structural design.

The charts provide
- 4^{th} order longitudinal & lateral transfer functions, plus
- Selected c ontrol response features (open or closed loop).

Also
- Approximate solutions for 4 sets of roots with varied natural frequencies & damping (or lack thereof).

$$F = F_{\text{ext}} - kx - c\frac{dx}{dt} = m\frac{d^2x}{dt^2}.$$

When no external forces are present (i.e. when $F_{\text{ext}} = 0$), this can be rewritten into the form

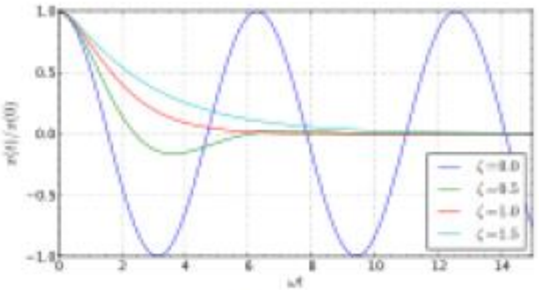
$$\frac{d^2x}{dt^2} + 2\zeta\omega_0\frac{dx}{dt} + \omega_0^2 x = 0,$$

where

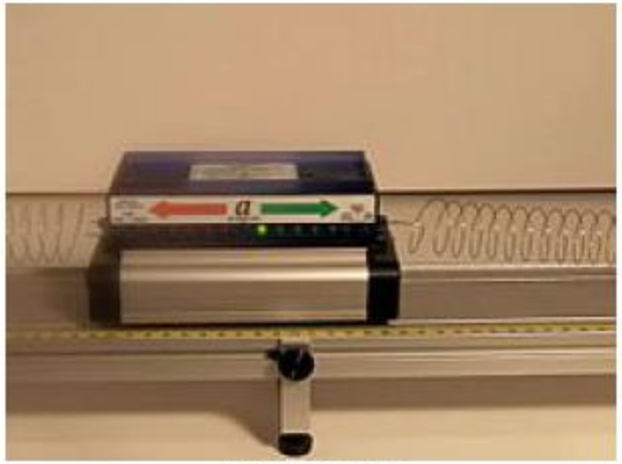
$\omega_0 = \sqrt{\frac{k}{m}}$ is called the 'undamped angular frequency of the oscillator' and

$\zeta = \frac{c}{2\sqrt{mk}}$ is called the 'damping ratio'.

The value of the damping ratio ζ critically determines the behavior of the system. A damped harmonic oscillator can be:



Dependence of the system behavior on the value of the damping ratio ζ



Play media

The “classical” theory of aircraft dynamics in cruise flight identifies

4 Basic Systems of Harmonic Oscillators in
2 sets of separable Differential Equations (approximated by constant coefficients)
revised for phases of flight.

1. Longitudinal: Pitch (θ), Axial (X) and Normal (Z) motions
   Providing Harmonic Oscillator Roots for
   Phugoid and
   Short Period

2. Lateral : Roll (ϕ), Yaw (Ψ) and Side (Y) motions
   Providing Harmonic Oscillator Roots
   Dutch Roll
   Secondary

In Other Words:
Stability and Control Analysis is
A Way of Surveying Overall Design

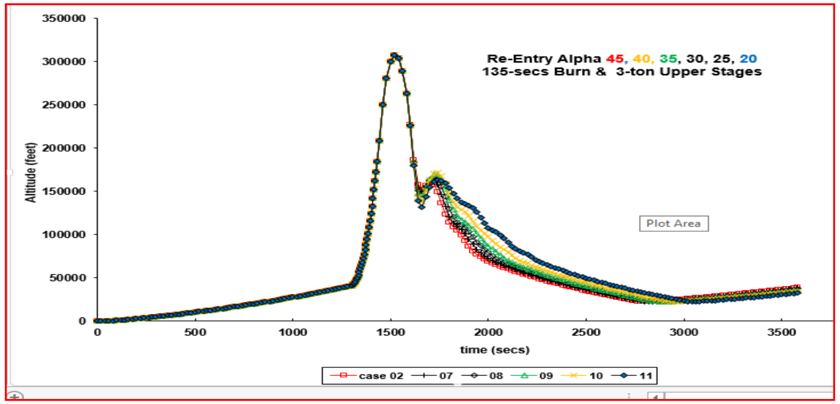
Simpler and More Complex Systems Can Be Derived for Special Flight Regimes (Coast and Accelerated).

Roots are derived from Mass Properties (Inertia Tensor, Aerodynamics and Equliibrium Forces
Controls are sized and modulated in forcing functions with System Dynamics analysis.

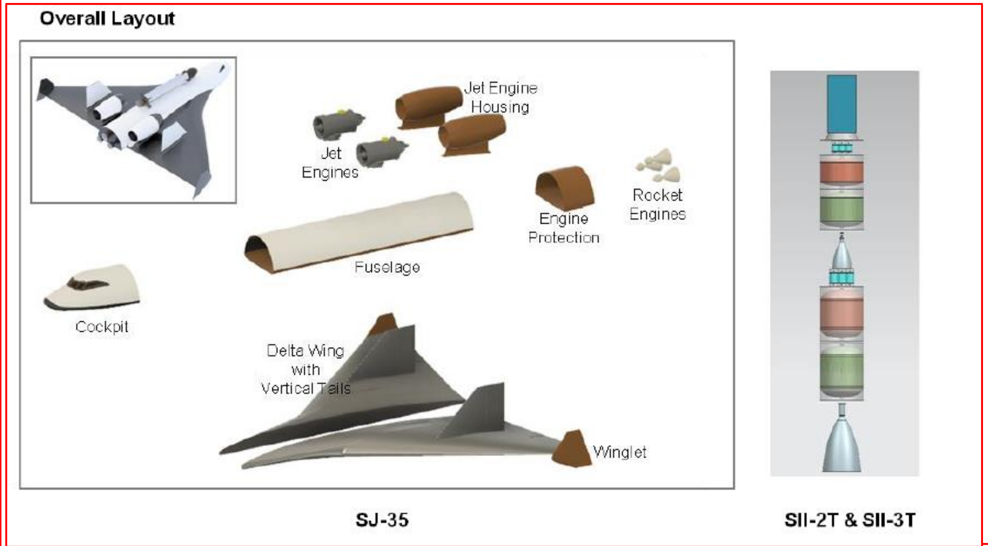
But to obtain the values which provide the roots, we need to compute, measure or estimate a host of vehicle features which change during flight (sector the results)

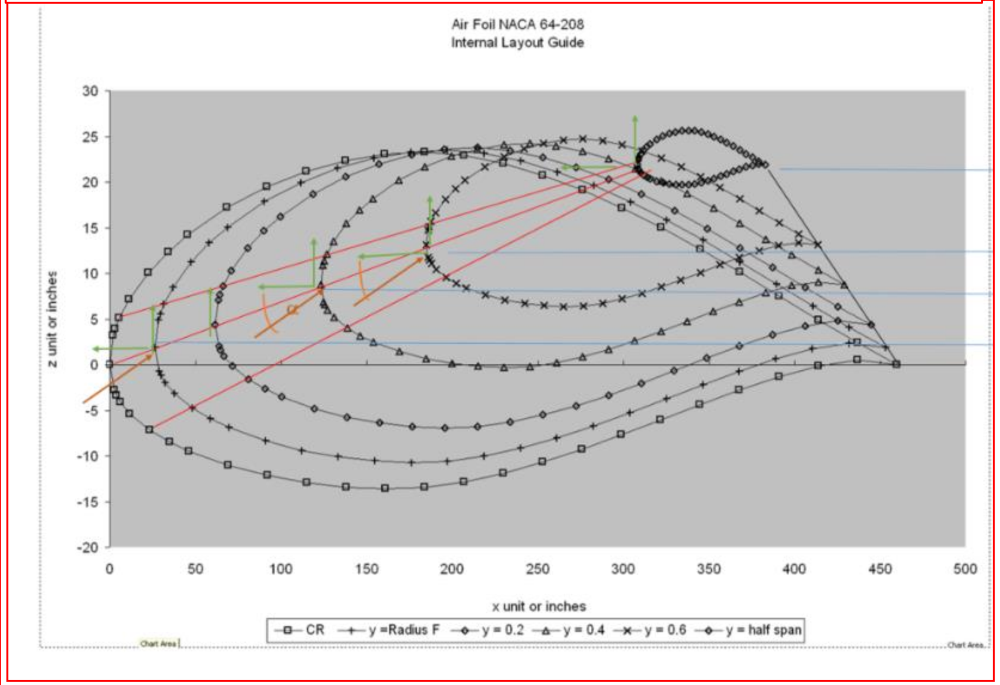
There is joy in the house each time
One of those entries is obtained – especially when
A derivation method is obtained as well.

Solution to the “handling problem” serves as evidence of a cumulative effort crossing several design disciplines:
- Aerodynamics,
- Structures,
- Mass Properties,
-Propulsion,
-Thermal
- Flight Performance.



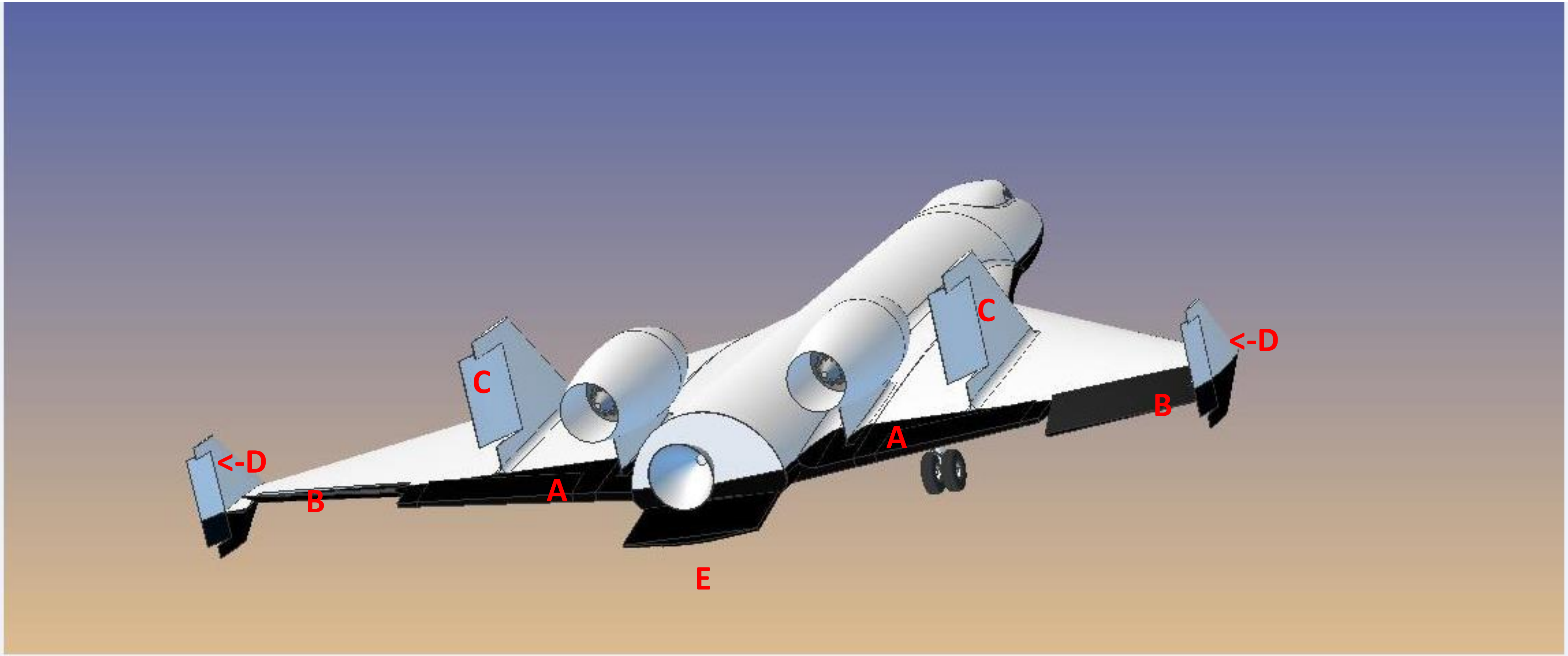
Also, we need to evaluate solutions obtained in light of mission requirements, cost, efficiency &risk. … **Now why do this at all?**



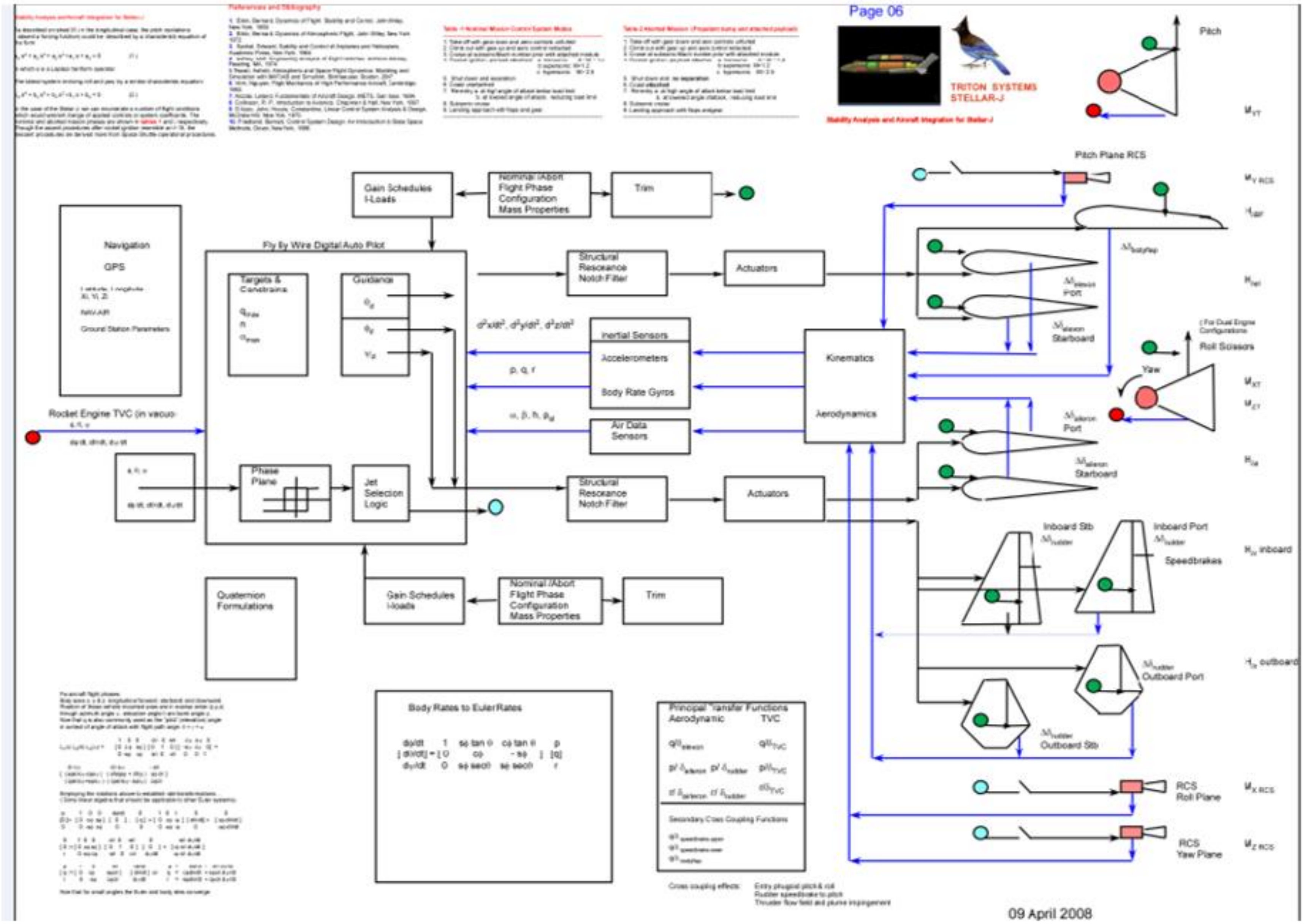


With Roots of the Longitudinal and Lateral Dynamics Evaluated for Flight Segments (Phases or Major Modes)

Beside Jet & Rocket Engines, **Aerodynamic Control Effectors** Include:
A & B)Elevons for Pitch and Roll (Y and X axes), inboard & outboard respectively
C) Vertical Tail Rudders for Yaw (Z axis), outboard winglet rudders (TBD) D).
Body flap(E), elevon and split rudder initial settings for “trim” for flight phase or major mode.



Stellar-J Flight Control



Stellar J
Defined as a rigid body
With changing
Center of Mass

$$\mathbf{R} = \frac{1}{M}\sum_{i=1}^{n} m_i \mathbf{r}_i,$$

Changing Moments &
Products of inertia

$$I_{11} = I_{xx} = \left(\sum_{k=1}^{N} m_k \left(y_k^2 + z_k^2\right)\right),$$

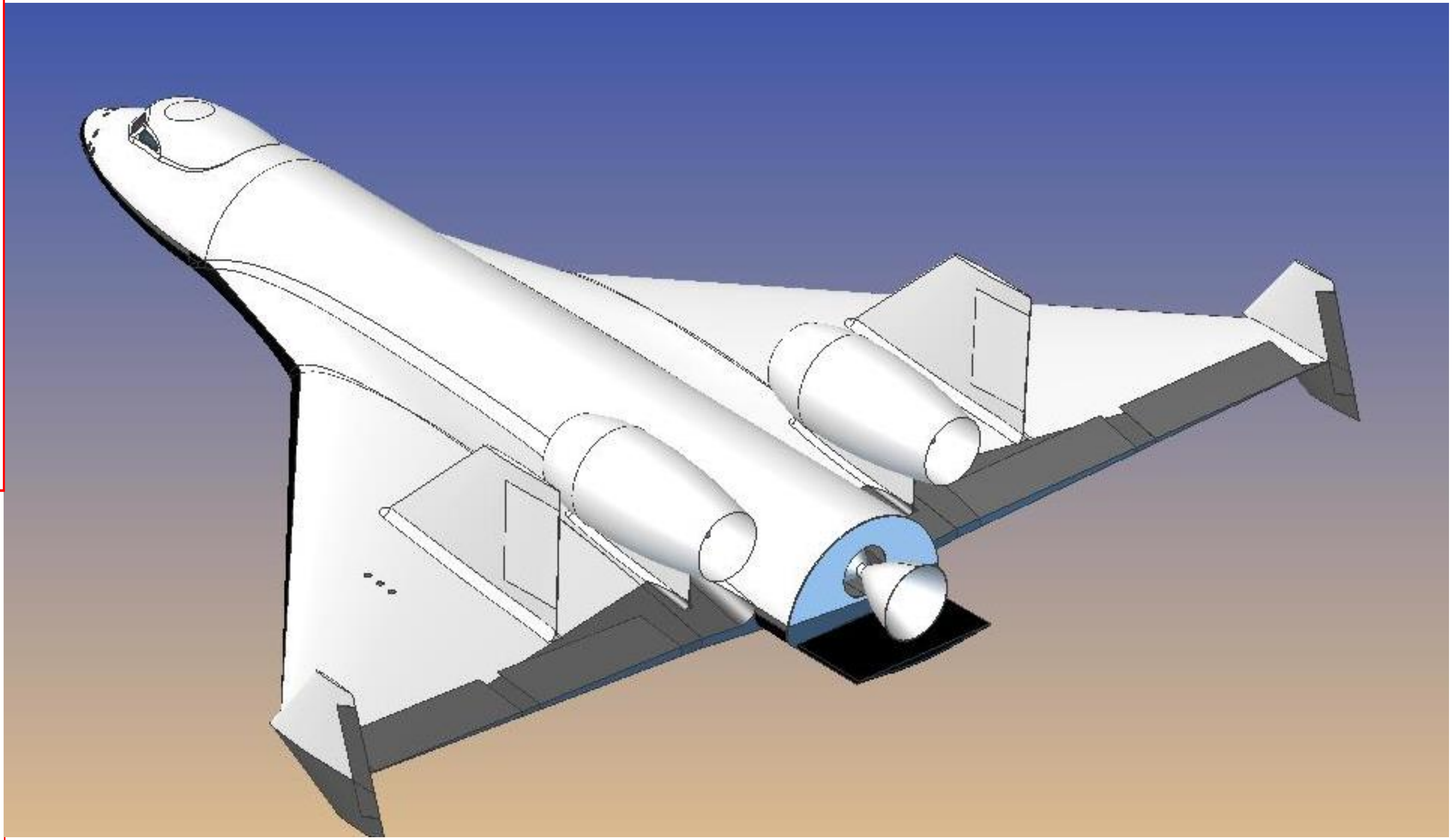
$$I_{22} = I_{yy} = \left(\sum_{k=1}^{N} m_k \left(x_k^2 + z_k^2\right)\right),$$

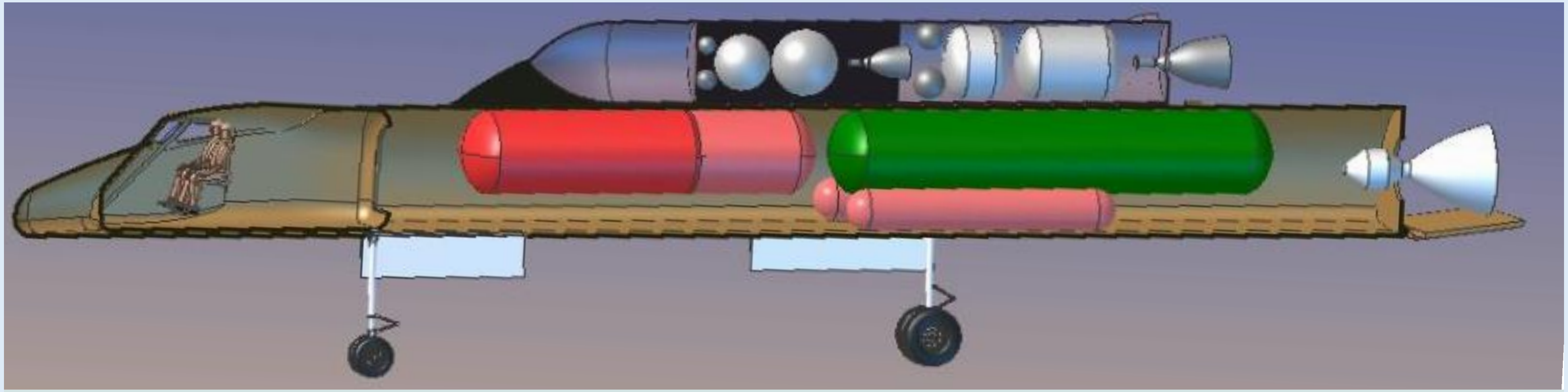
$$I_{33} = I_{zz} = \left(\sum_{k=1}^{N} m_k \left(x_k^2 + y_k^2\right)\right),$$

$$I_{12} = I_{21} = I_{xy} = -\left(\sum_{k=1}^{N} m_k x_k y_k\right),$$

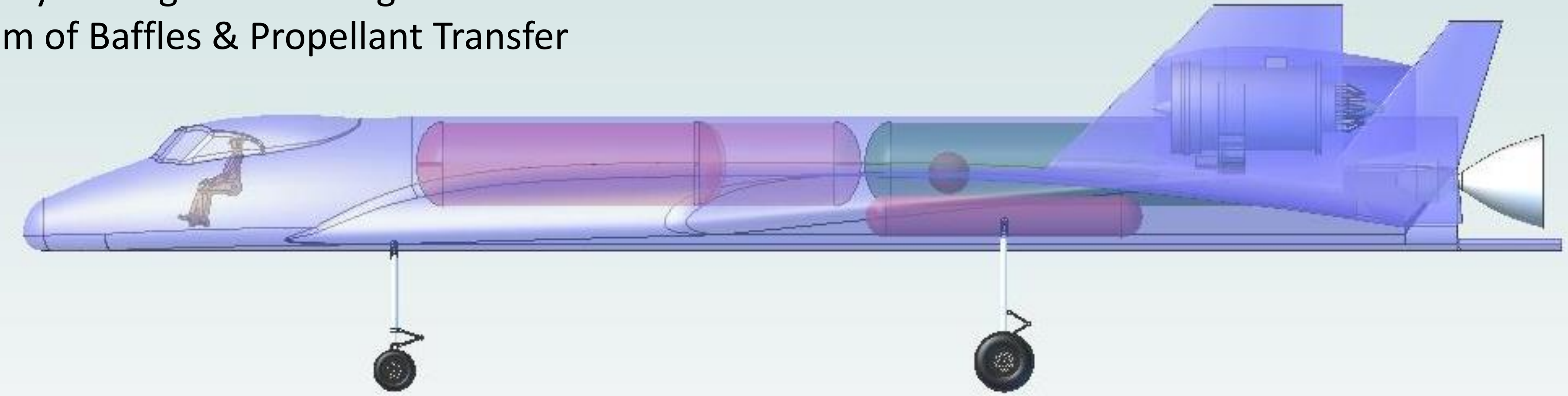
$$I_{13} = I_{31} = I_{xz} = -\left(\sum_{k=1}^{N} m_k x_k z_k\right),$$

$$I_{23} = I_{32} = I_{yz} = -\left(\sum_{k=1}^{N} m_k y_k z_k\right).$$

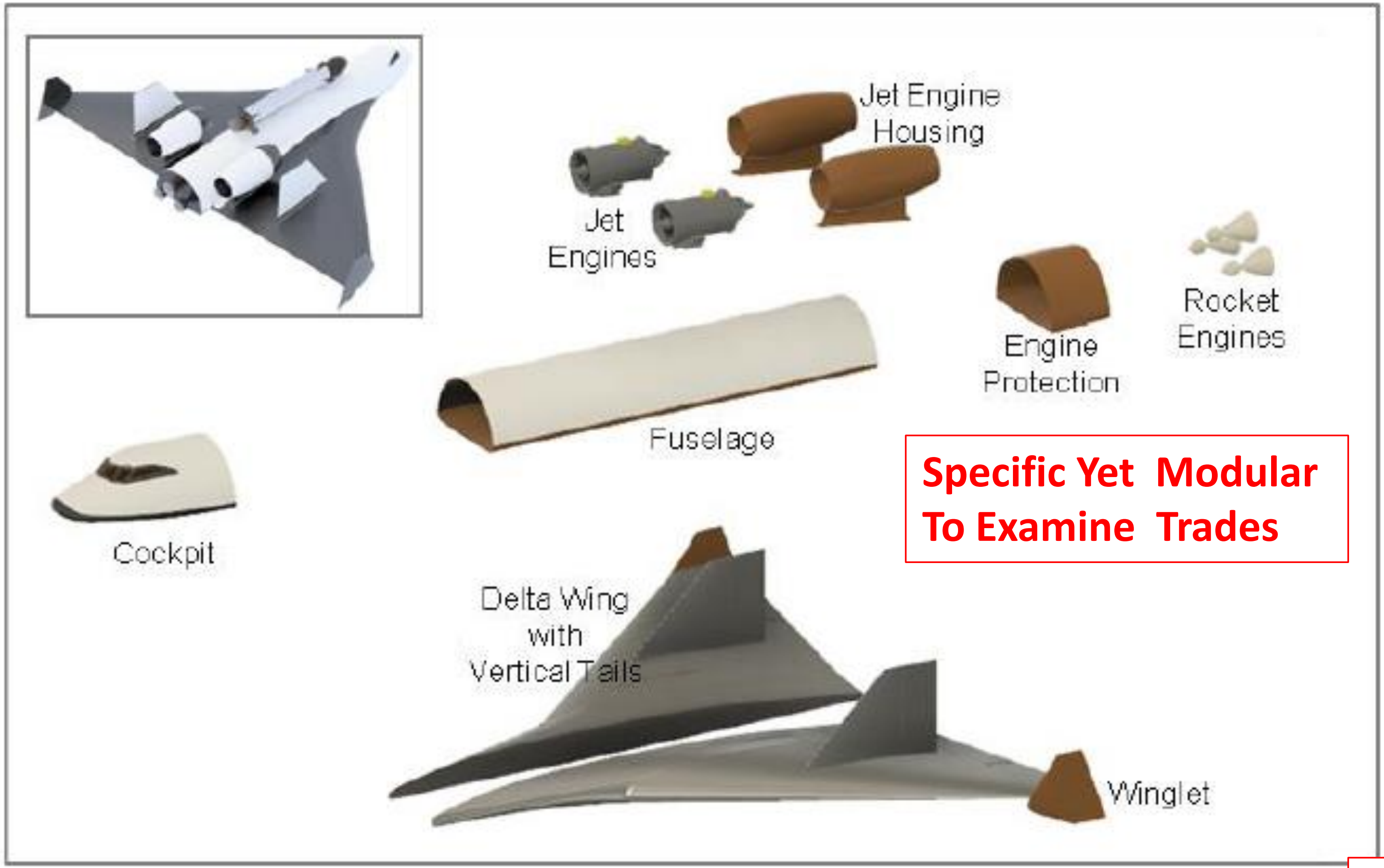




Center of Gravity Management in Flight
Includes System of Baffles & Propellant Transfer

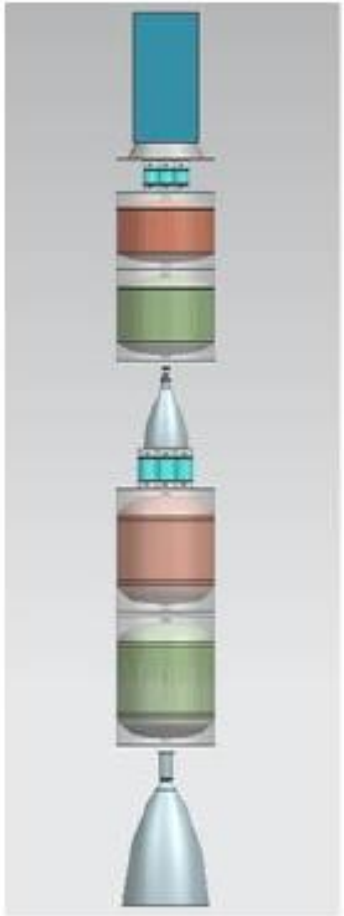


Overall Layout

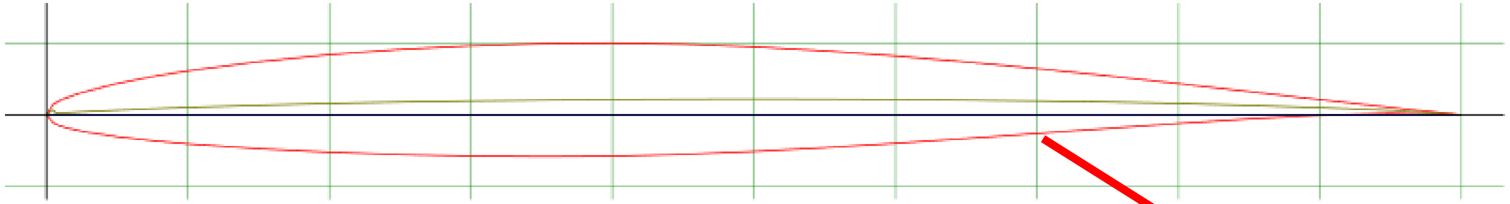


Specific Yet Modular To Examine Trades

SJ-35



Expendable Upper Stage System IIA & IIB



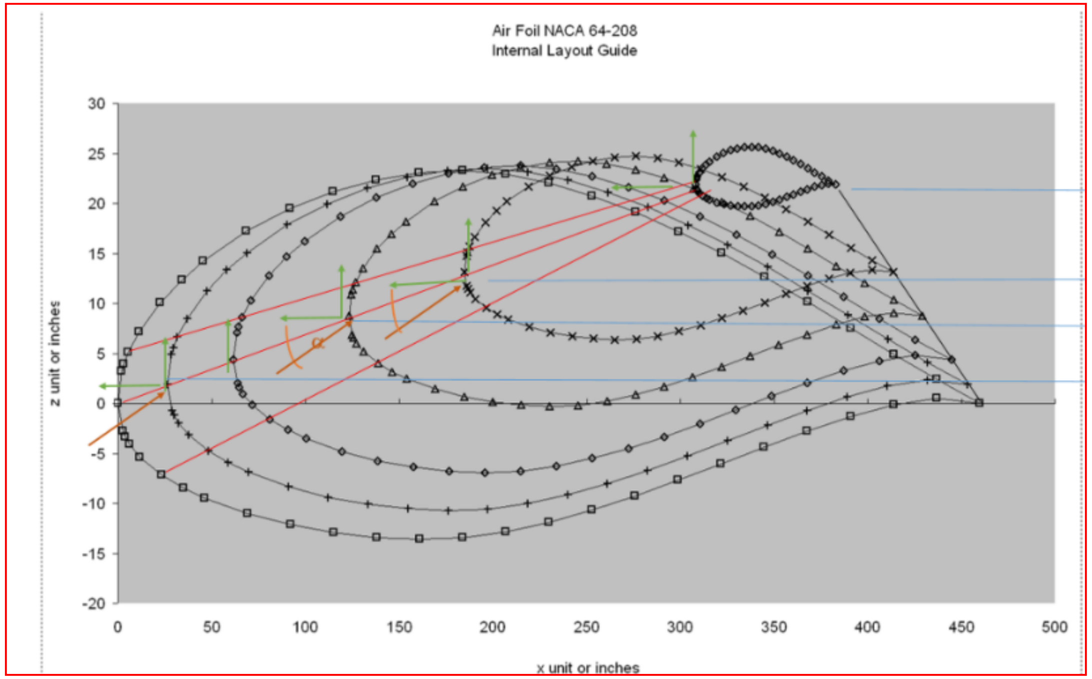
Modularity: Wing Elements

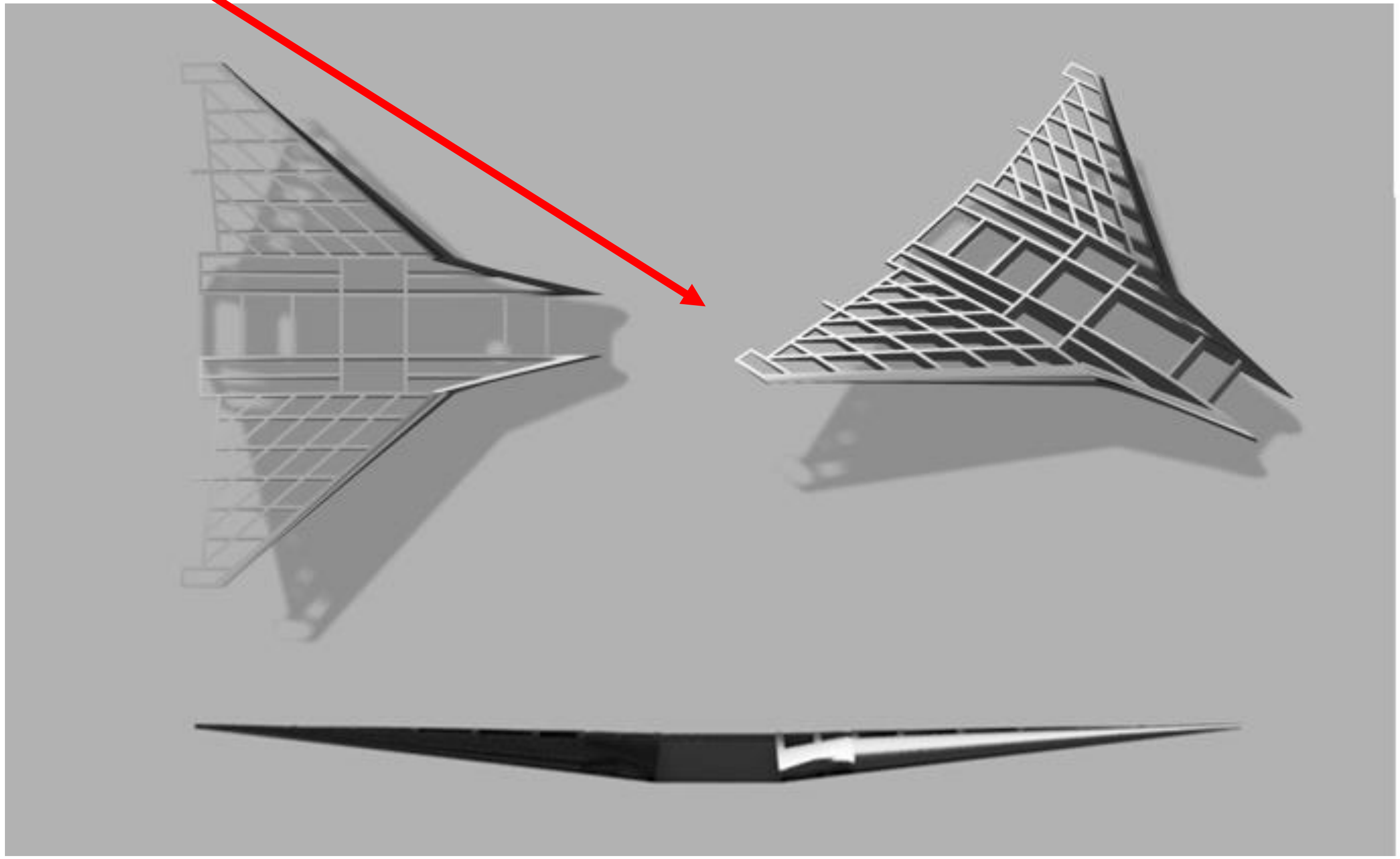
Plan to Trade Out:

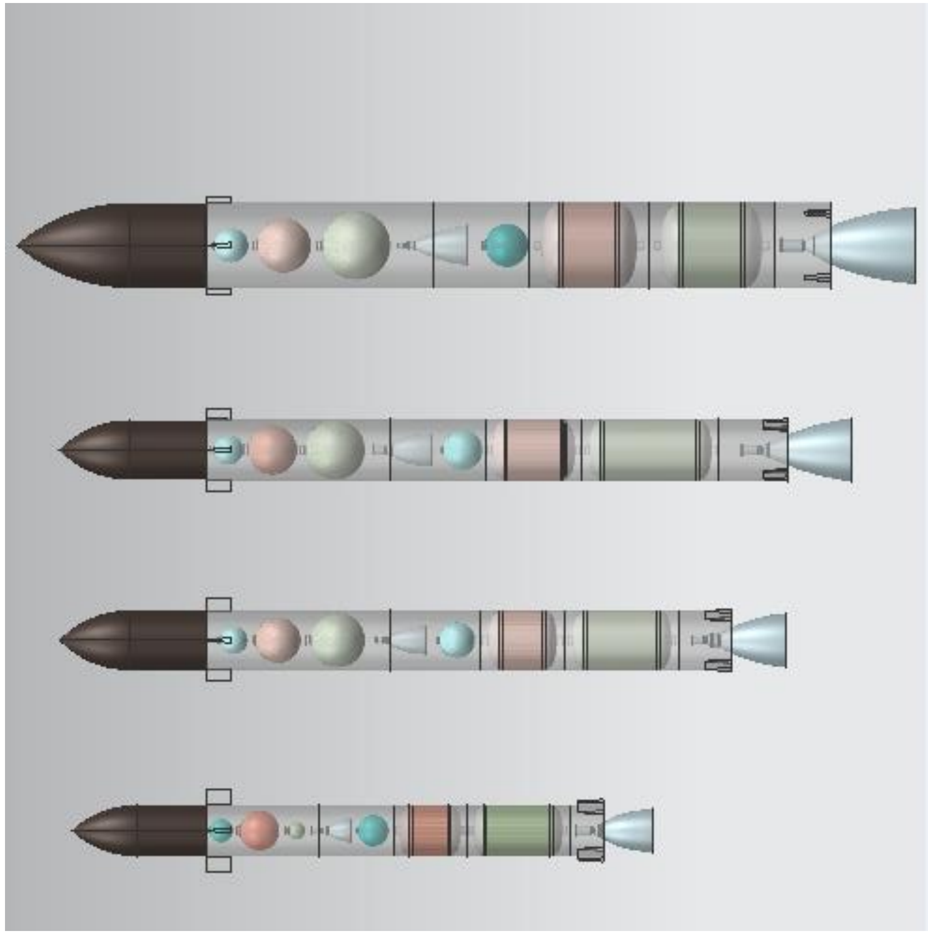
- Airfoil,
-Leading & Trailing Edge Sweep ,
-Root & Tip Chord,
- Main Spars, Ribs, Cut-Outs & Flaps

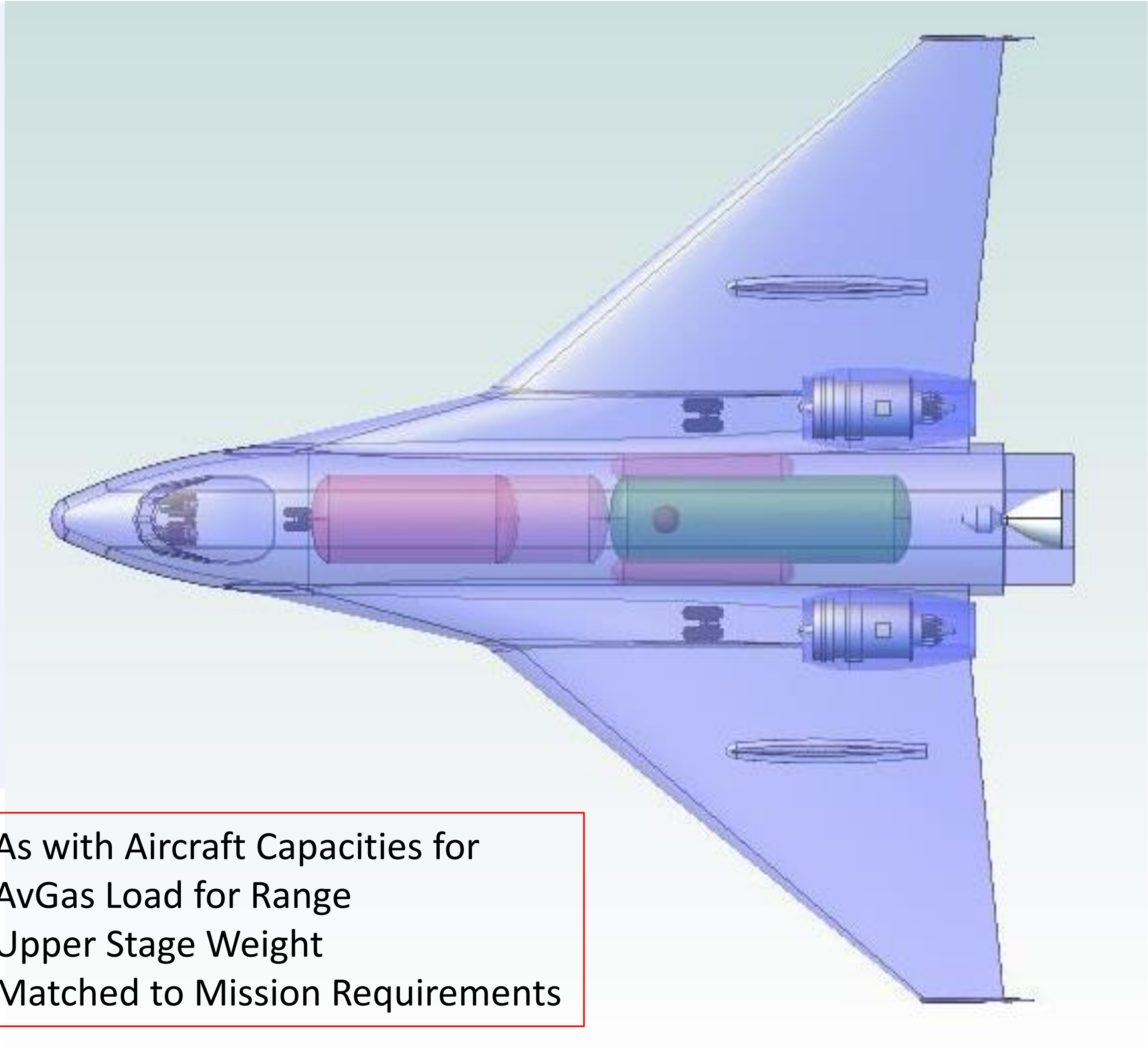
NACA 64-208 (naca64208-il)

NACA 64-208 - NACA 64-208 airfoil



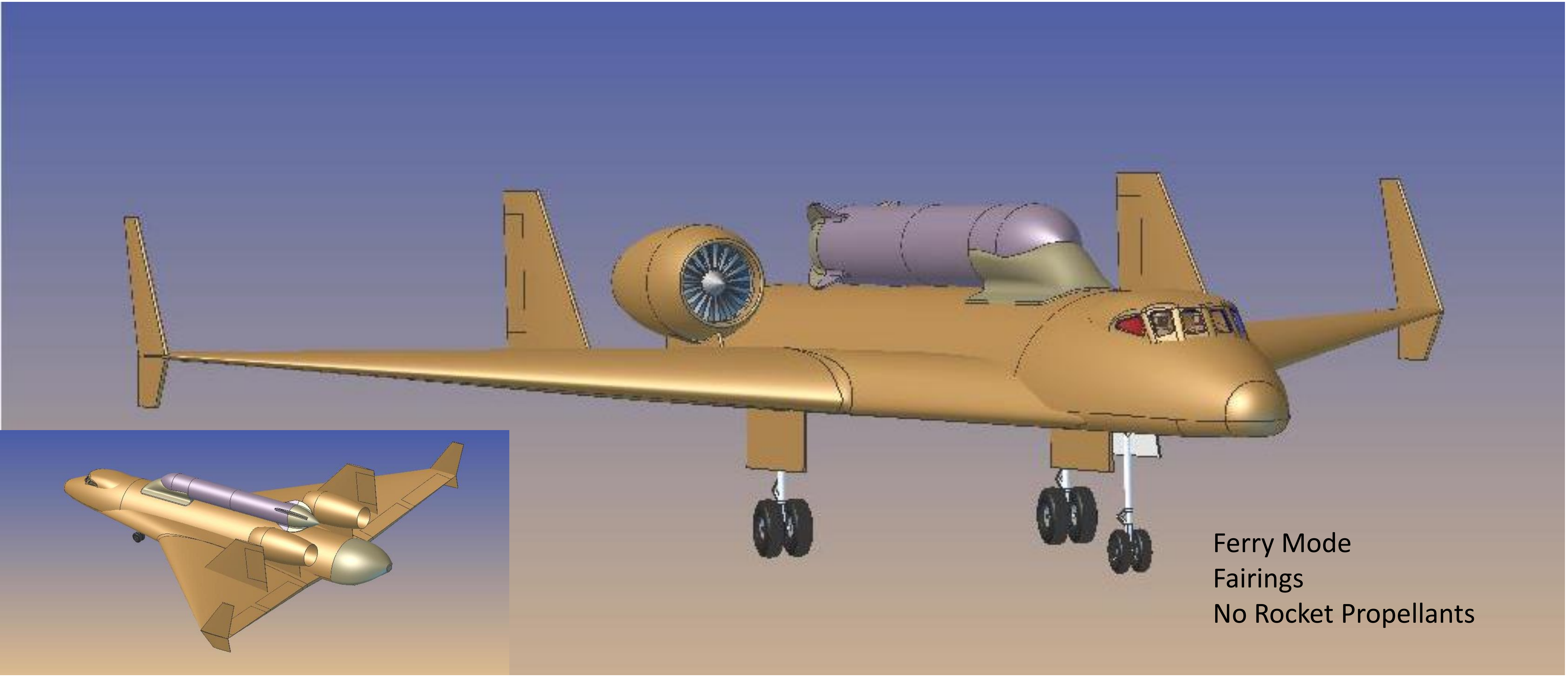






Based on Mission or Development Phase
Expendable Upper Stage System IIA & IIB
Vary in Diameter, Length & Mass

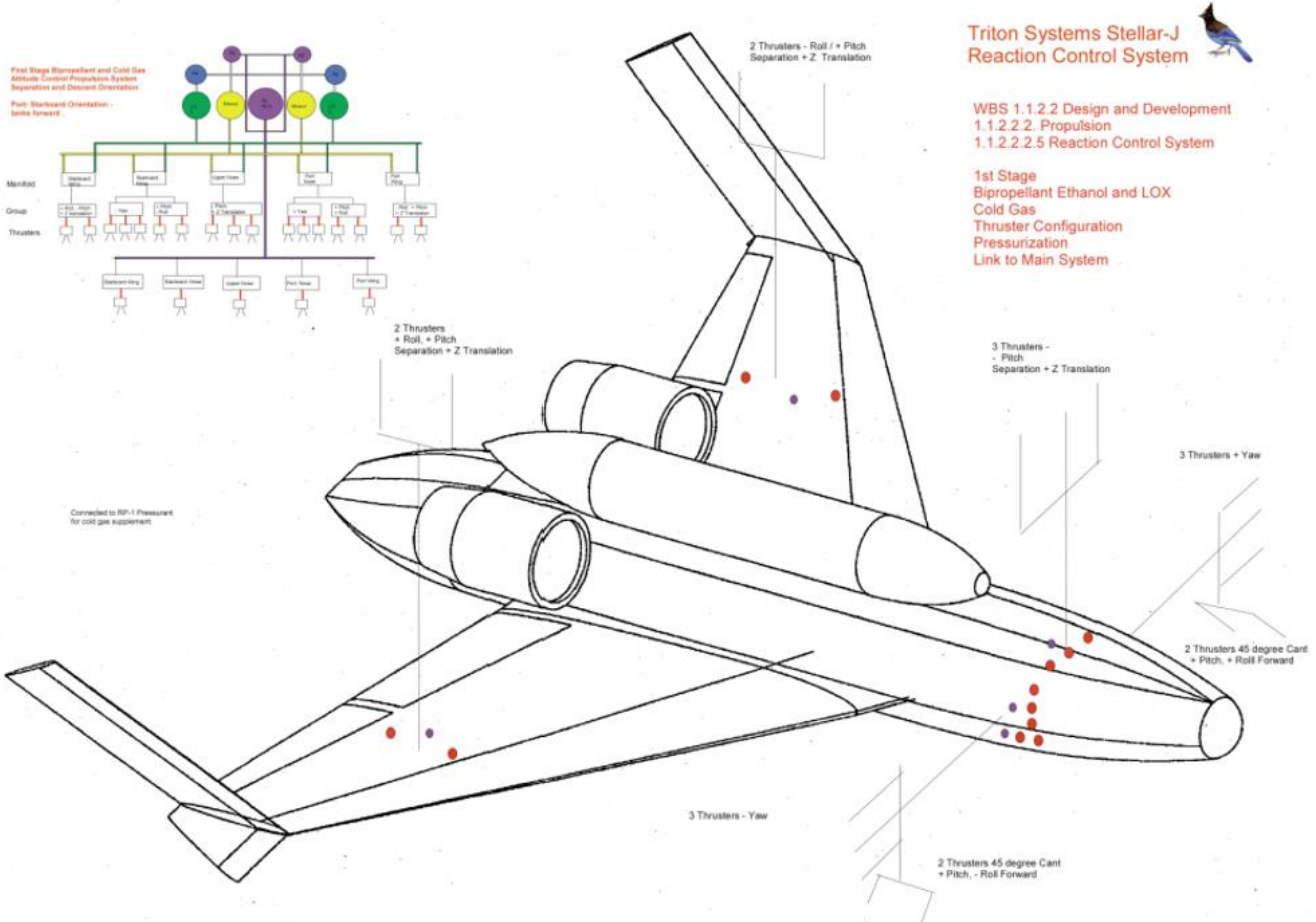
As with Aircraft Capacities for
AvGas Load for Range
Upper Stage Weight
Matched to Mission Requirements


Ferry Mode
Fairings
No Rocket Propellants

Triton Systems Stellar-J Reaction Control System

WBS 1.1.2.2 Design and Development
1.1.2.2.2. Propulsion
1.1.2.2.2.5 Reaction Control System

1st Stage
Bipropellant Ethanol and LOX
Cold Gas
Thruster Configuration
Pressurization
Link to Main System

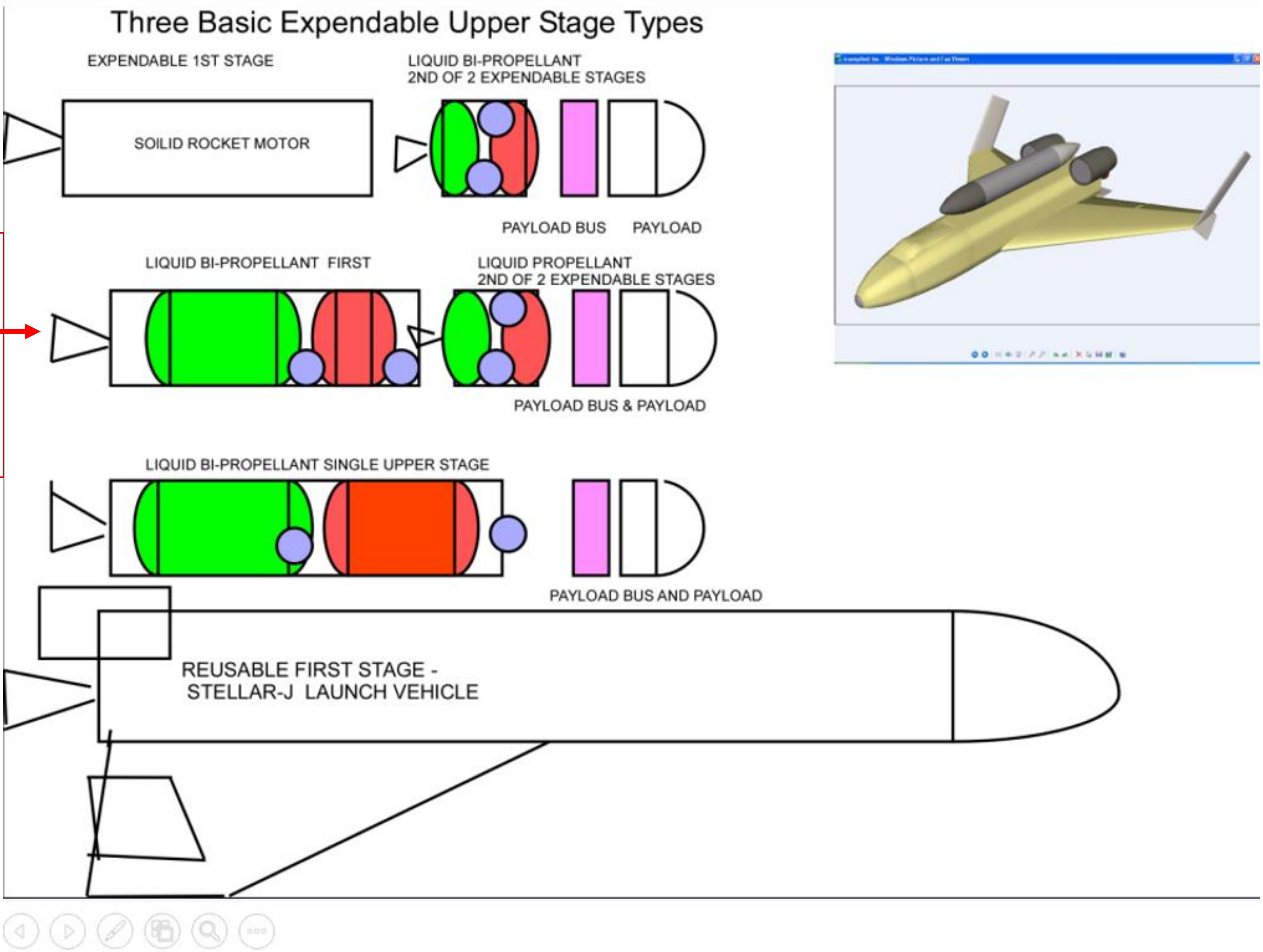


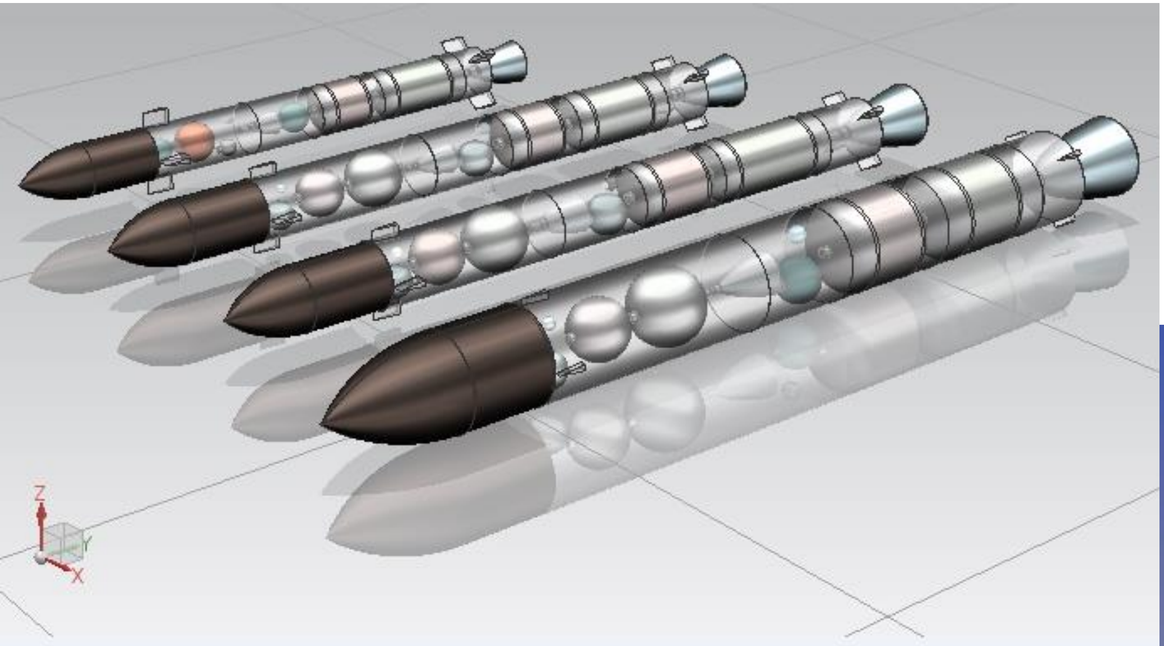
Reference Upper Stage Configuration

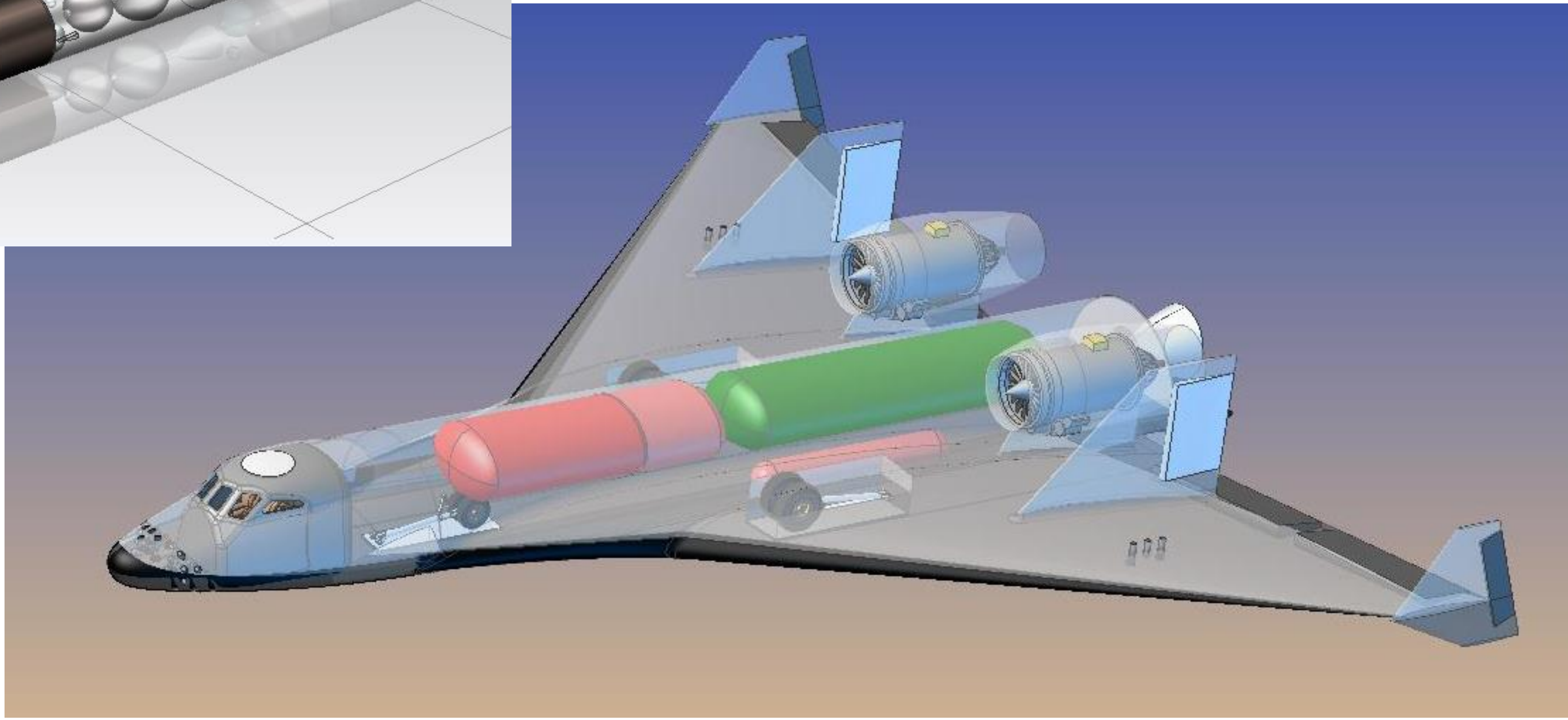
“IIA & IIB”

IIA Standardized

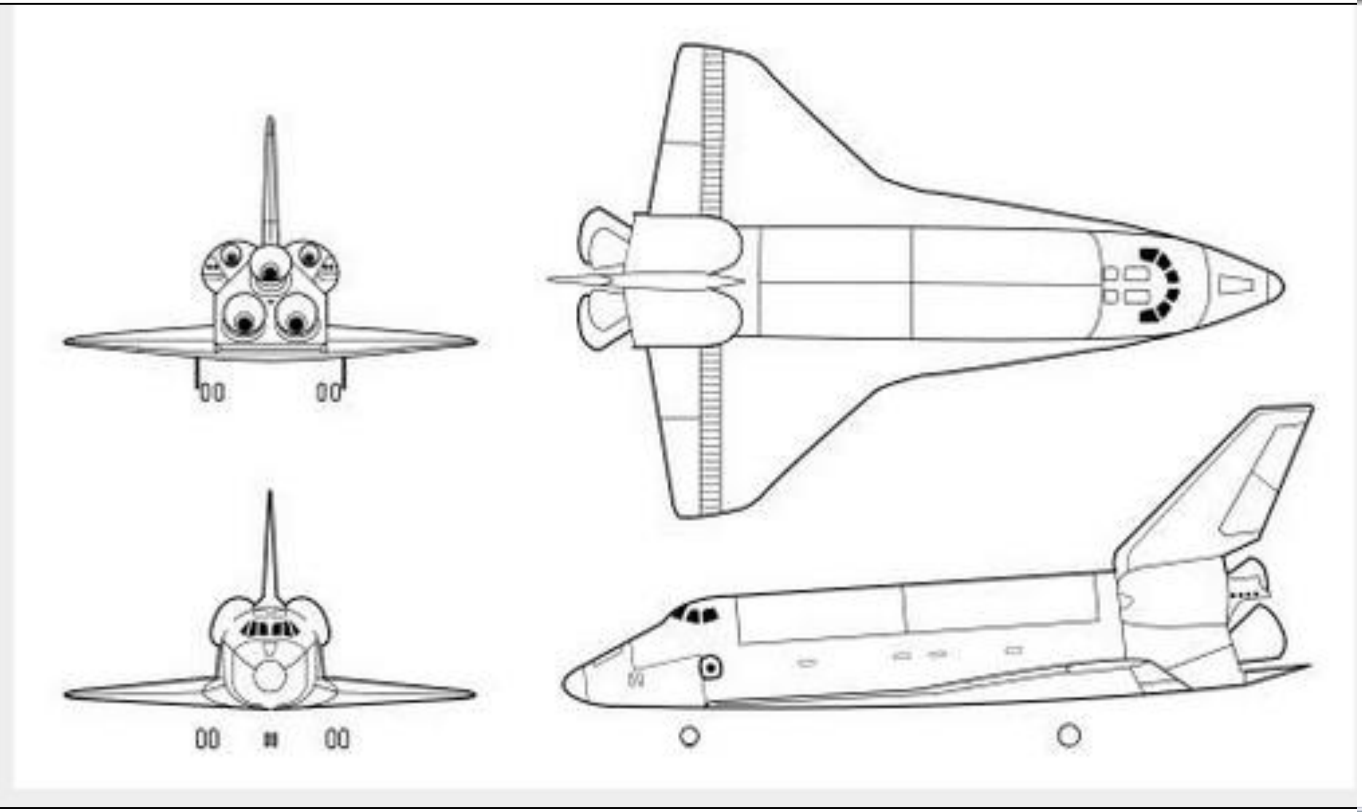
IIB Adapted to Mission

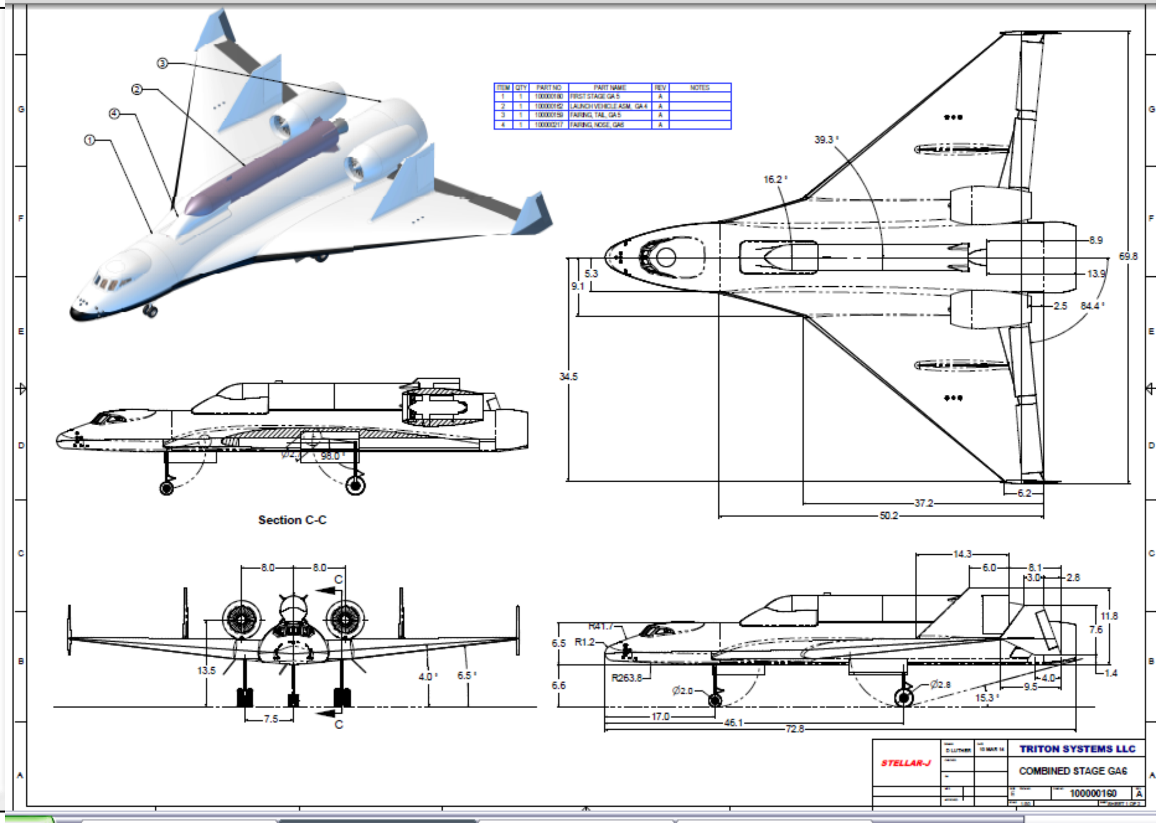


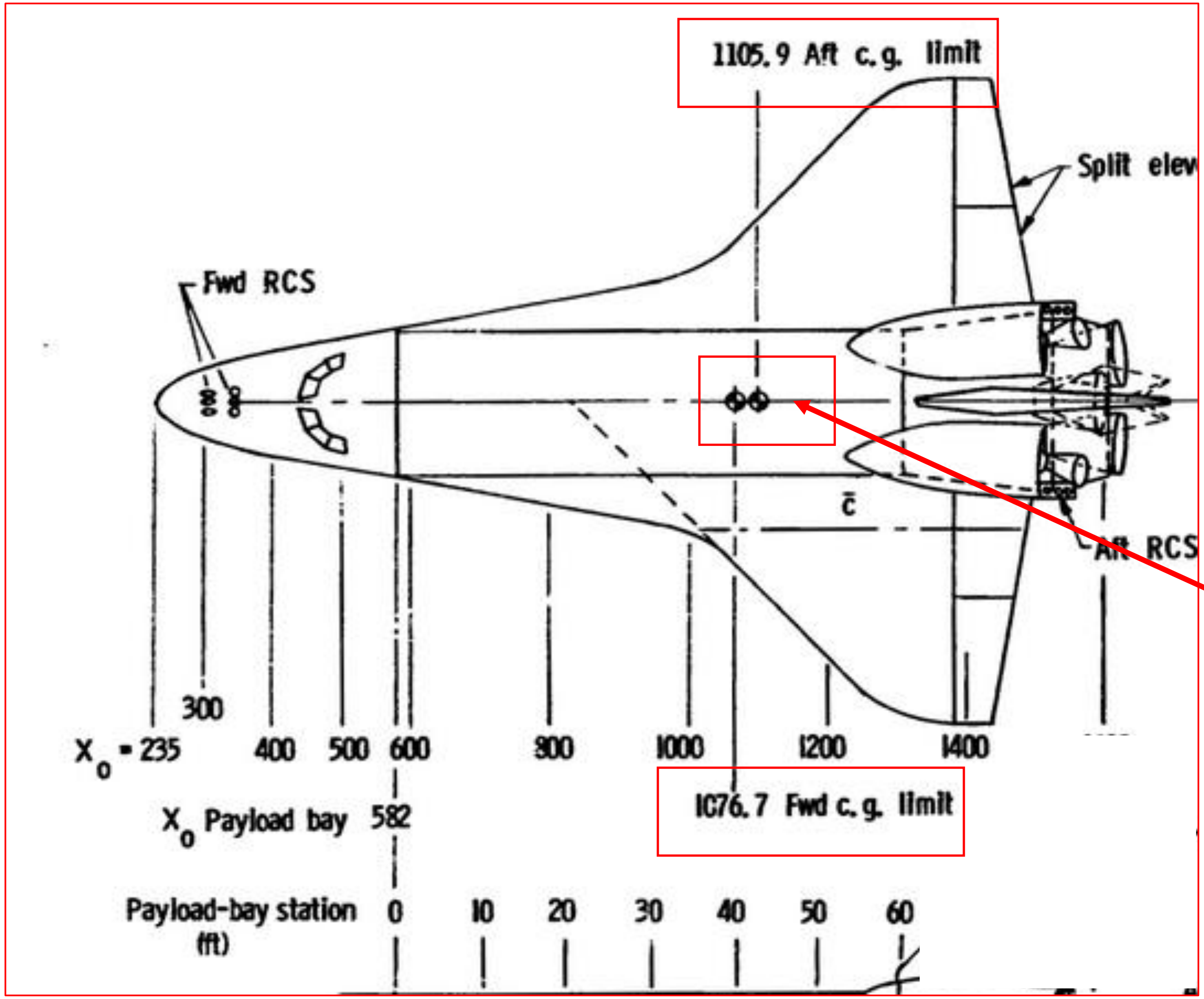




Space Shuttle Orbiter Aero
Applied to Stellar-J







Orbiter CG Limits

Entry Interface, M=3.5, & Touch-Down

1076.7 to 1109.0 inches (32 inches)

Abort (RTLS) & Post ET-Sep 1079 to 1109

Sample Pre-Flight (1990) Estimates*

Nominal	F35	F37	F39	F40
ET Sep	1106.3	**1116.5**	1110.4	1100.3
EI	1081.8	1090.8	1082.0	1087.4
M=3.5	1080.5	1089.3	1080.4	1079.7
TD	1081.9	1090.9	1081.8	1081.1

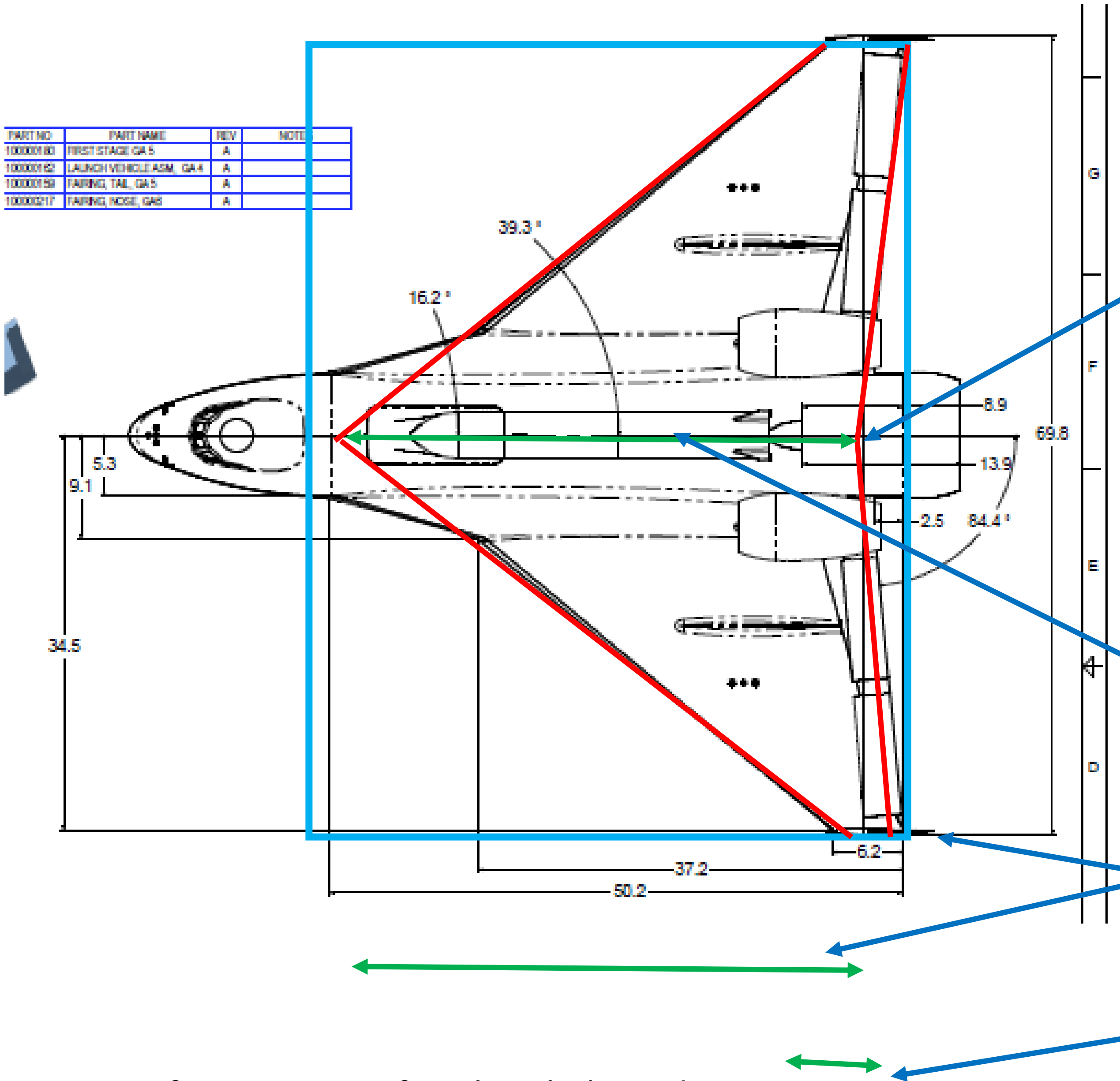
Orbiter Length = 1365 inches

2/3L = 910 X_O = **1145 inches**

Nominal Moment arm: 36” to 69”

How do dispersions affect control surface trim?

*Shuttle Systems Weight and Performance NTSTS-09095097, June 19, 1990, NASA JSC

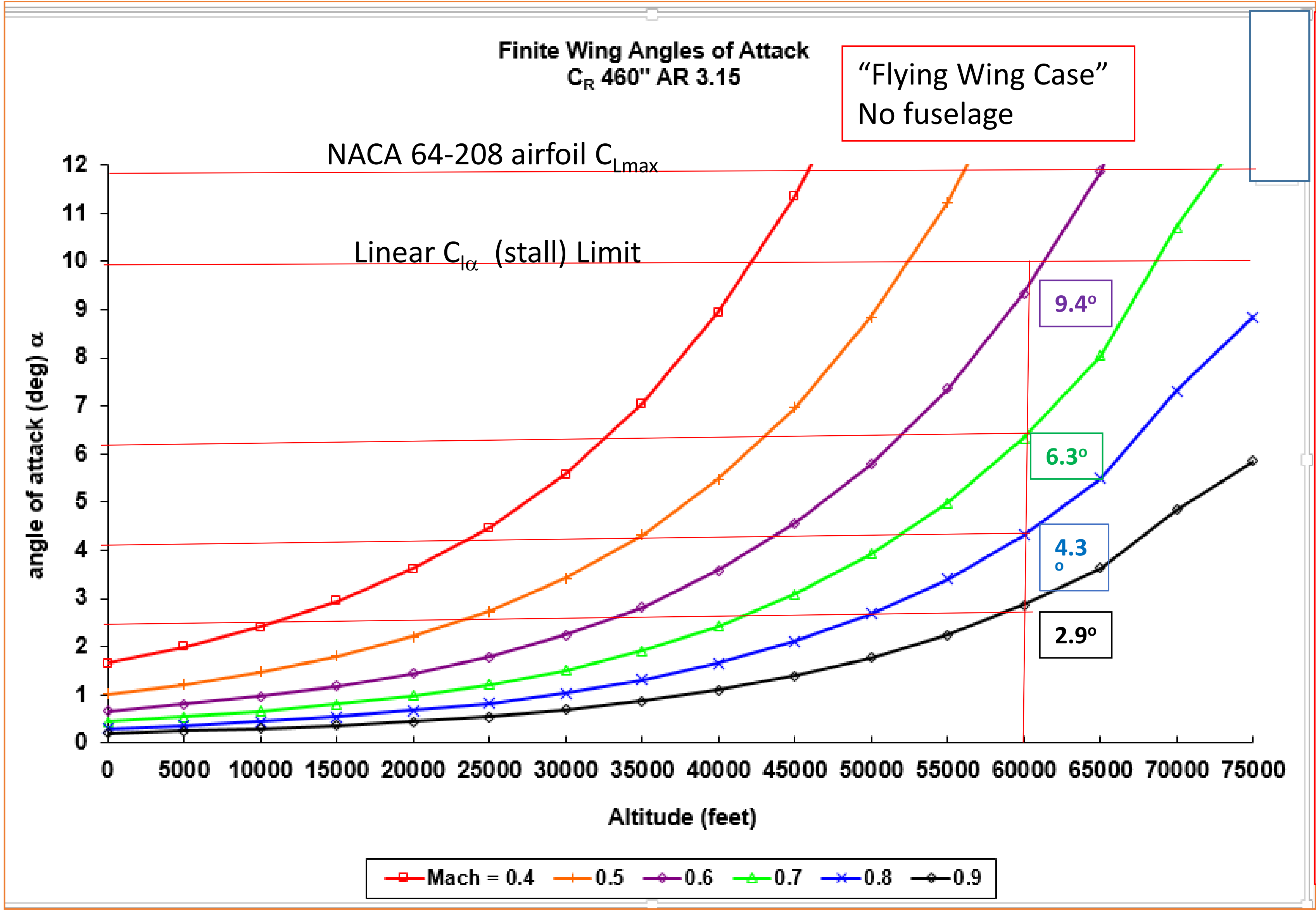


Base of root chord
At aft end of Stellar J
Reference System Coordinates
X, Y, Z: 965, 0, 180
This is required to connect
Aero calculations based
On aero center – cg divided
By mean chord.
Calculations used in determined
Static and dynamic stability.

Root Chord along x axis.

Tip chord at end of span or y = half span.

Reference Area for Shuttle based on same
Convention of integrating simple chord as function of y from tip to tip given fixed leading and trailing edges.



Max Wgt =70,000 lb = Lift

$L = 1/2\rho(h)\ v^2\ S\ C_L$

$= ½\ \rho(h)\ (a(h)\ M)^2\ C_{L\alpha}\ \alpha$

$C_{L\alpha} =$

$a_0 A_R / [a_0/\pi + (A_R/\cos\Lambda_{1/2}\}^2 + (a_0/\pi)^2 - (A_R M_{inf})^2)^{1/2}]$

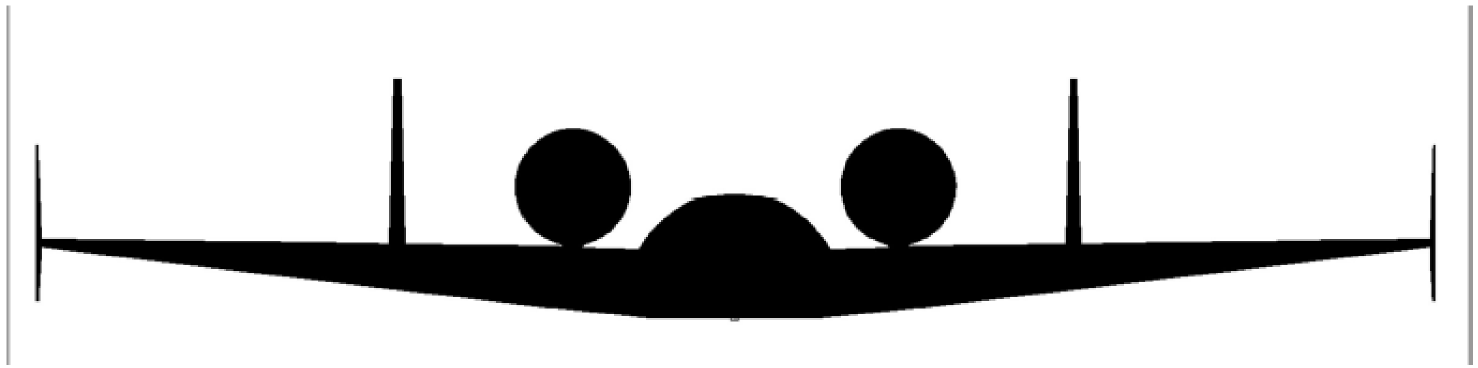
A_R = Aspect ratio chord to tip (b^2/S)

a_0 = 2-D air foil zero Mach $c_{L\alpha 0}$

$\Lambda_{1/2} = (\Lambda_{le} - \Lambda_{te})/2$

Reference atmosphere densities, temperature & speed of sound.

NACA 64-208 airfoil



0° Angle of Attack – Without SIIA/B

Frontal Area: 32662 in^2

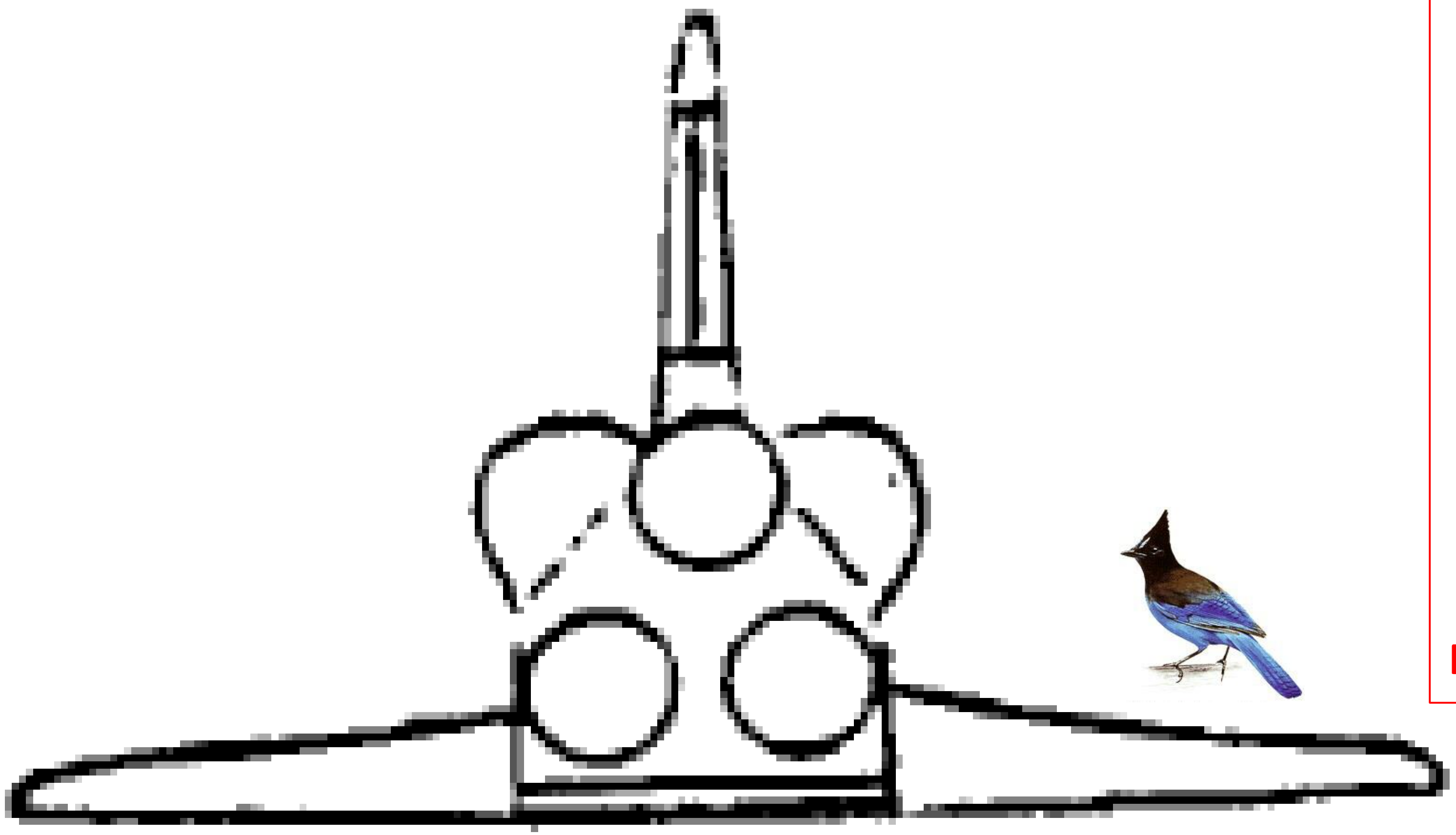
Perimeter: 2809 in

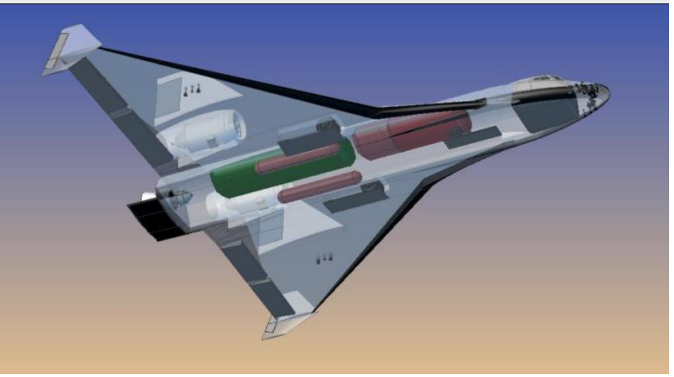
Base Area w.r.t. "Center Line":

Stellar-J	**226.8 ft^2**
Orbiter	**436.7 ft^2**
Ratio:	**0.51935**

S_{REF} Wing Reference Area

Stellar-J	**1697.8 ft^2**
Oribter	**2690.0 ft^2**
Ratio:	**0.6312**





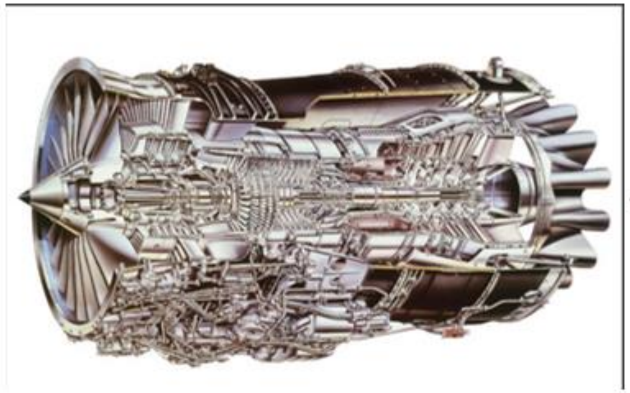
Jet Engine Trades
Rolls Royce & Other Candidates
Images, Parameters &Analysis Methods

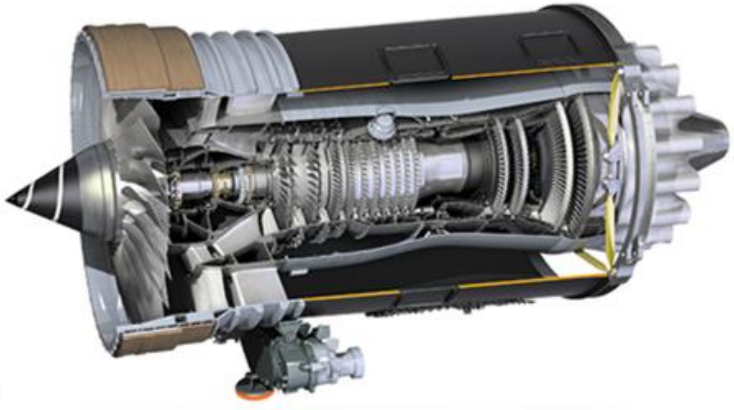
Select the Best Jet Engine (Combination) for Stellar-J Configuration & Mission

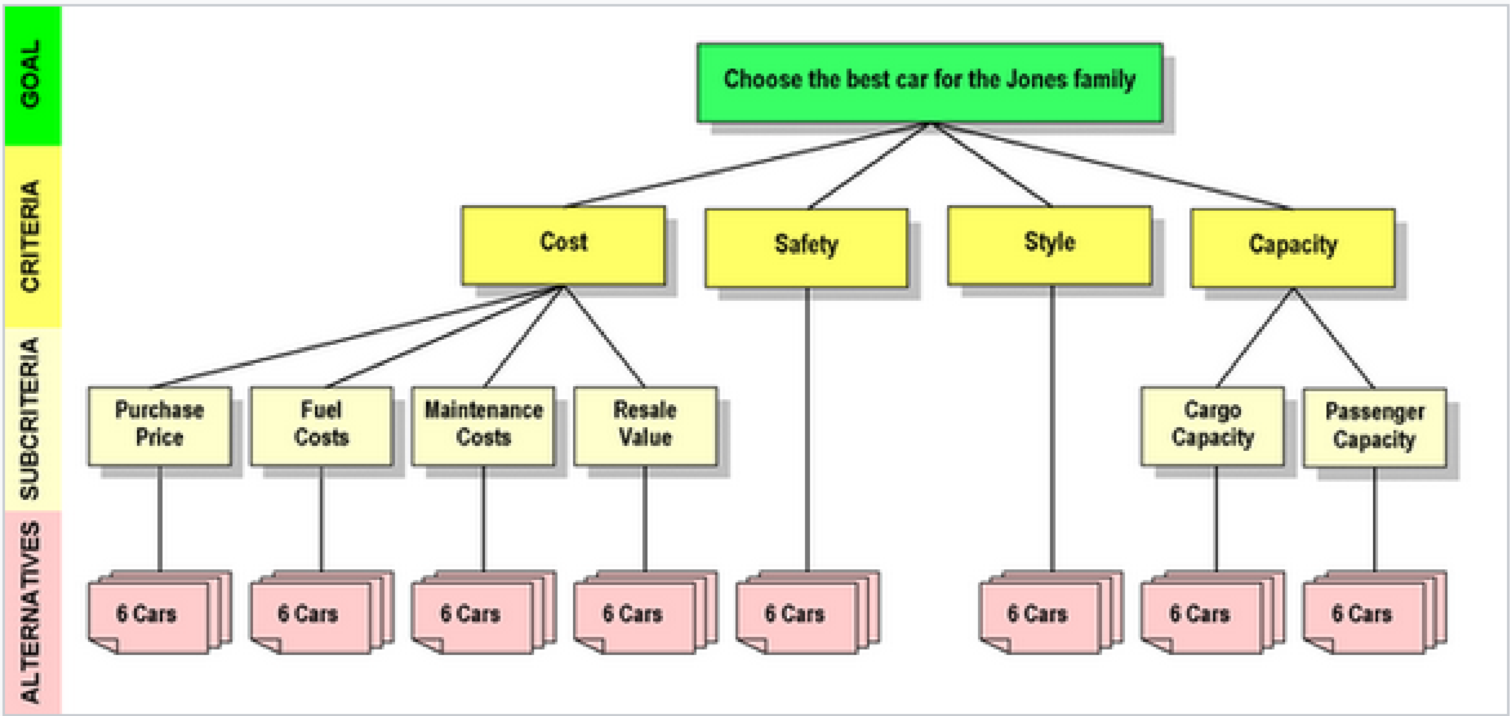
Based on Performance, Constraints, Costs,

Using Saaty's Analytical Hierarchy Procedure (AHP)

Analogous to a Family Selecting a New Car

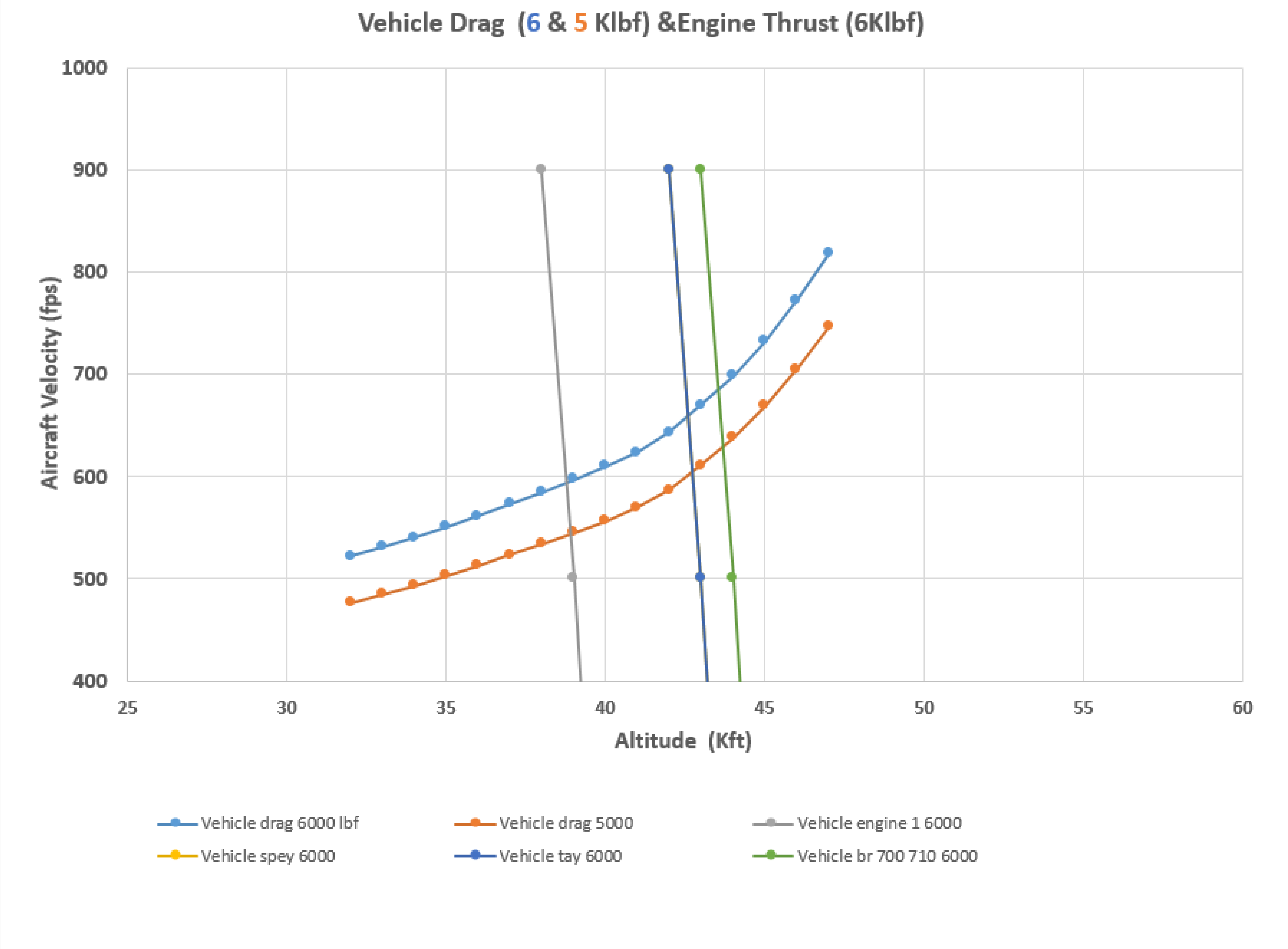






AHP hierarchy for the Jones family car buying decision. The goal is green, the criteria and subcriteria are yellow, and the alternatives are pink. All the alternatives (six different models of Hondas) are shown below the lowest level of each criterion. Later in the process, each alternative (each model) will be rated with respect to the criterion or subcriterion directly above it.

Family Car Purchase	Stellar-J Jet Engines
Criteria or Sub Criteria	
1. Cost	1. Climb to High Altitude &/or High Mach (<1.0)
2. Safety	2. Low Installation Weight
3. Style	3. Low Fuel Consumption
4. Capacity	4. Low Cross Section
	5. Operating Life
	7. Cost
	8. Range after Re-Entry
	9. Restart Behavior & Reliability

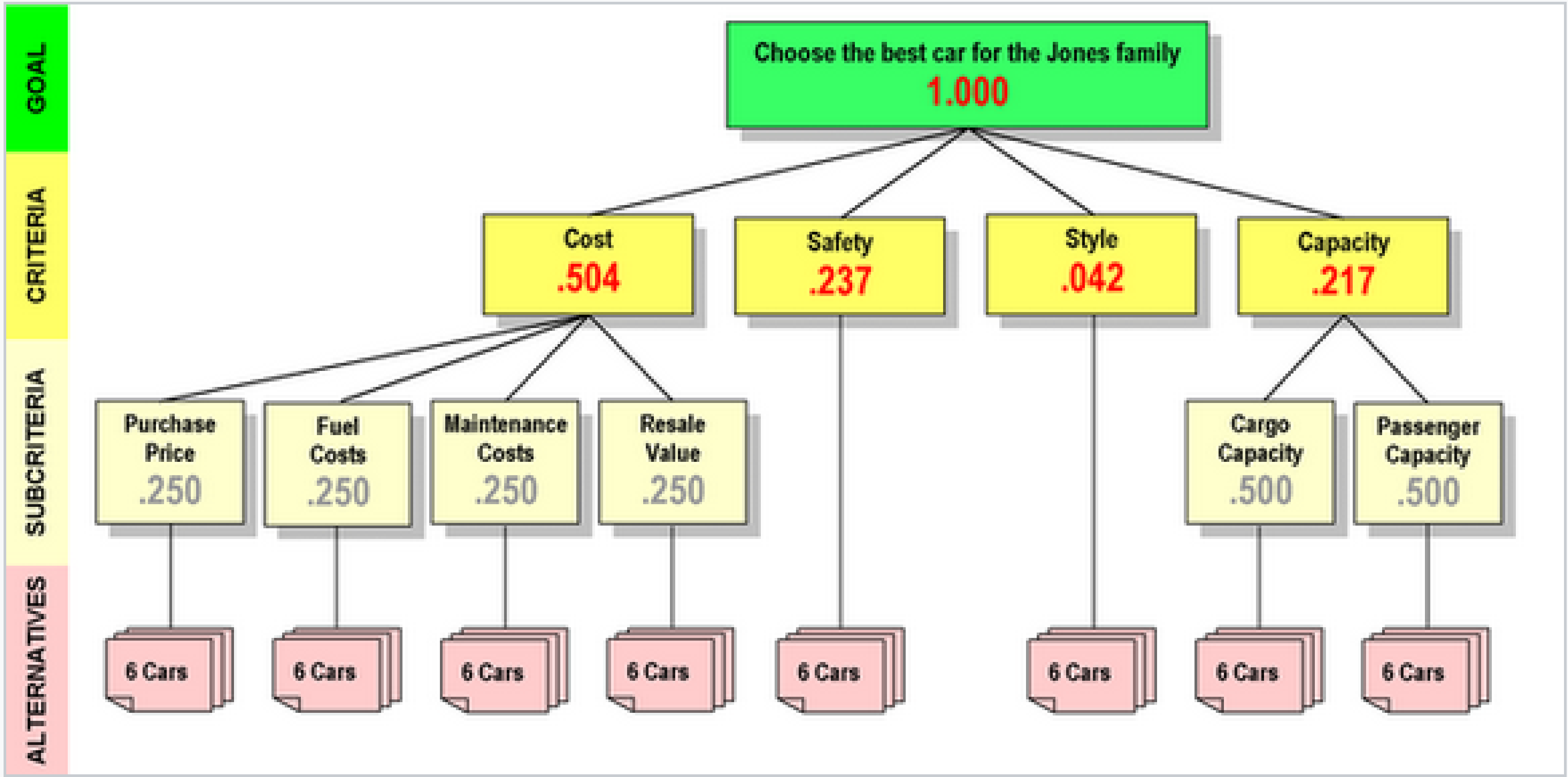


Vehicle Drag (6 & 5 Klbf) &Engine Thrust (6Klbf)
Aircraft Velocity (fps)
1000
900
800
700
600
500
400
25
30
35
40
45
50
55
60
Altitude (Kft)
Vehicle drag 6000 lbf
Vehicle drag 5000
Vehicle engine 1 6000
Vehicle spey 6000
Vehicle tay 6000
Vehicle br 700 710 6000

Engine Data : Two Engine Trades - Gulfstream IV/450 Baseline to allow margin for drag

Name	Spey 511-8	**Tay 611 8C**	BR 700-710
Type	Axial Flow Fan	**Axial Flow Fan**	Axial Flow Fan
Dry Wgt – Tail Pipe (lbs)	2483	**2951**	3520
Max Length (inches)	110	**95**	87
Max Diameter (inches)	32.5	**44**	52.9
Overall Pressure Ratio at Max Power	18.4	**15.8**	25.5
SFC at Max Power	0.8	**0.69**	0.39
Bypass Ratio	0.6	**3.2**	4.0
Max Power at Sea Level Thrust (lbf)	11,400	**13,850**	14,000-17,000*
Combustor Type	Can-Annular	**Can-annular**	Annular
Number of Turbine Stages(Low, High Pressure)	2,2	**2,3**	2,2
Number of Fan Compressor Stages	5,12	**1,3,12**	1,12
Application	Gulfstream II&III	**Gulfstream IV/450**	Gulfstream V/550
Max Cruise (knots/mach)	500	**488**	**?**
Max altitude (ft)	45,000	**45.000**	51,000

* 15,385 lbf with G-550



AHP hierarchy for the Jones family car buying decision. The Criteria have been pairwise compared, and their new priorities are shown. (Before the comparisons, each Criterion had a default priority of 0.250.) Note that the priorities still total 1.000, and the priorities for the subcriteria have not changed. The family has said that Cost is quite important to them, Style is relatively unimportant, and Safety and Capacity are each roughly half as important as Cost, with Safety having a slight edge over Capacity. Family members can look at these priorities and see how they feel about them. If they are uncomfortable about something, they can redo their pairwise comparisons.

Jet Engine Selection
Similar, but Different

1. Capability to deliver High altitude with heading Speed to reduce Delta V.
2. Weight of Engine
3. Fuel Consumption
4. Range after Satellite Deployment
5. Cost per Unit.
6. Reliability (Re-Start)
7. Operating Life

Inter-Related? … Yes.

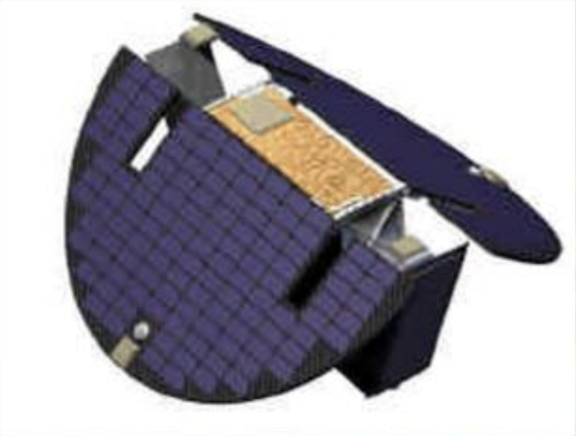
Weight and normalization?

Market Research

For 21 years Utah State University has hosted the Small Satellites Conference

A 2007 Summary:

62 exhibitors included
- satellite & component vendors, satellite users,
- large and small aerospace companies,
- university, government & private research units domestic and foreign
- 78 presented papers represented with 137 cited organizational units



Cicero Spacecraft

-Broad Reach Engineering reported on CICERO: a constellation of 100 30- kg satellites. CICERO will perform radio occultation measurements of earth's atmosphere for weather and hurricane prediction. Discussions with the vendor about this 3rd generation project indicates: Hardware is in assembly, but no launcher is signed on for deployments over the next decade.

- World small satellite leader Surrey Satellite Center (UK) described several similar prospective programs. About a dozen universities reported on individual satellite programs…

Annual satellite launch rates (monitored by Futron Research) do not match systems introduced.
Satellite backlogs (~500) with introduction of new satellite concepts would go even higher.
But some waiting for launch slots or low cost opportunities will eventually fade away;
Research and development teams, organizations and sponsors will eventually move on
-Unless more rapid, lower cost means of satellite launch are made available.
The need for such a launch system is a recurring conference theme.

Satellite Market

In 2004 Triton Identified 8 Primary Markets for 4 Vehicle Systems

Vehicle Types and Configurations

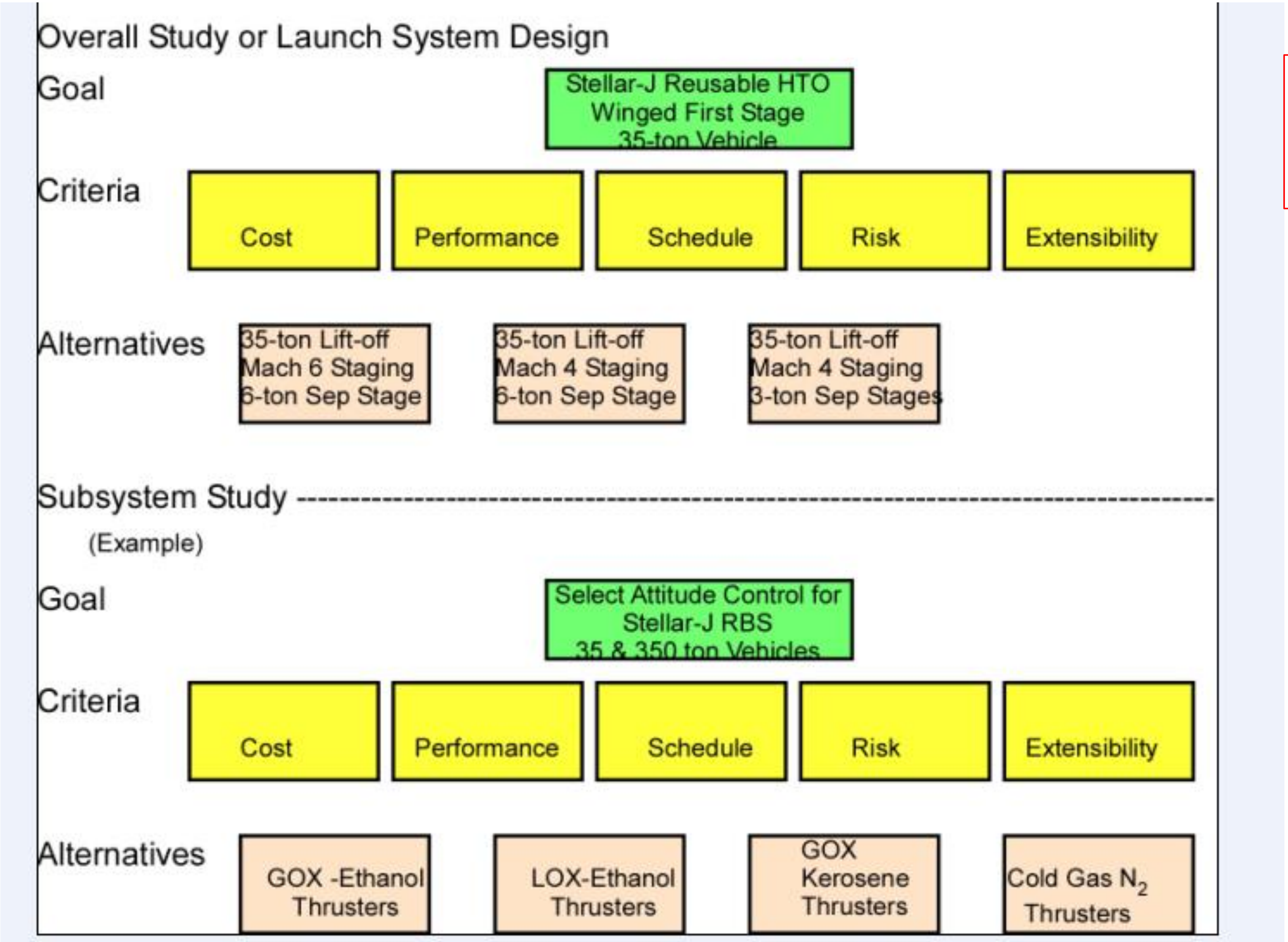
LEO Satellite Payloads (lbs):	100-200	1,000	2,000	10-20,000	-
	A	B	C	D	
Mission Model for Revenue	Demo	35-ton	70-ton	350-ton	+ Orbiter
1. Sounding Rockets	x	x			
2. Sub-Orbital Tourism	?	x	x		
3. Micro-Satellites	X	X	x		
4. LEO Satellite Constellations	X	X	x		
5. LEO Space Platforms				x	
6. Rendezvous Payloads		x	x	x	x
7. Sortie and Return Payloads		x	x	x	x
8. Rescue Standby		x	x	x	x

Primary Markets Missions (1-8 and Subsets)
Graded on Scale of 1 –5 with 8 Parameters
(Red X: High return on low initial investment)

1. Market Maturity
2. Market Demand
3. Price Margin over Mission Cost
4. Potential Volume
5. Mission Procedural Complexity
6. Mission Hardware Complexity
7. Regulatory Barriers
8. National Economic &/ Strategic Security


Gear Down
STS-135
Atlantis
21 July 2011

Backup Notes



Moe Miller would often tell us Project issues boiled down to Performance, Schedule & Cost

POST2 (History) was developed from the original POST software starting in 1995 -
the 2006 NASA Software of the Year Runner-Up.
POST development began in the early 1970's in partnership with the Martin Marietta Co. as a space shuttle simulation program. ..Improved with capabilities added w.r.t.
vehicle modeling,
trajectory simulation,
targeting and optimization.

Considerations Here for Constrained/Iterated Paths of Defined Vehicles
Not Constrained /Iterated Vehicle Designs

3- and 6-DOF POST can optimize & target ascent, entry, and orbital trajectories since the early 80's.

The ability to analyze only one vehicle within a single simulation is insufficient to properly study advanced launch vehicle concepts such as a multi-stage to orbit vehicle with fly-back boosters. **(....???)**

Traditionally POST users had to do several trajectory simulations and optimize the problem external to POST.

POST II can solve this problem within a single trajectory simulation.

Example: determining where launch vehicle expended stages or jettisoned portions of entry and orbital vehicles impact the attracting body while including the primary vehicle in the simulation permits faster evaluations such as is **necessary to support spacecraft and launch vehicle operations.**

Deflection $$y(x) := y_1 + \theta_1 \cdot x + \frac{M_1 \cdot x^2}{2\,E \cdot I_x} + \frac{R_1 \cdot x^3}{6\,E \cdot I_x} - (x > a) \cdot \left(\frac{W}{6\,E \cdot I_x} (x - a)^3 \right)$$

Moment $$M(x) := \left(\frac{d^2}{dx^2} y(x) \right) \cdot E \cdot I_x$$

Shear $$V(x) := \left(\frac{d^3}{dx^3} y(x) \right) \cdot E \cdot I_x$$

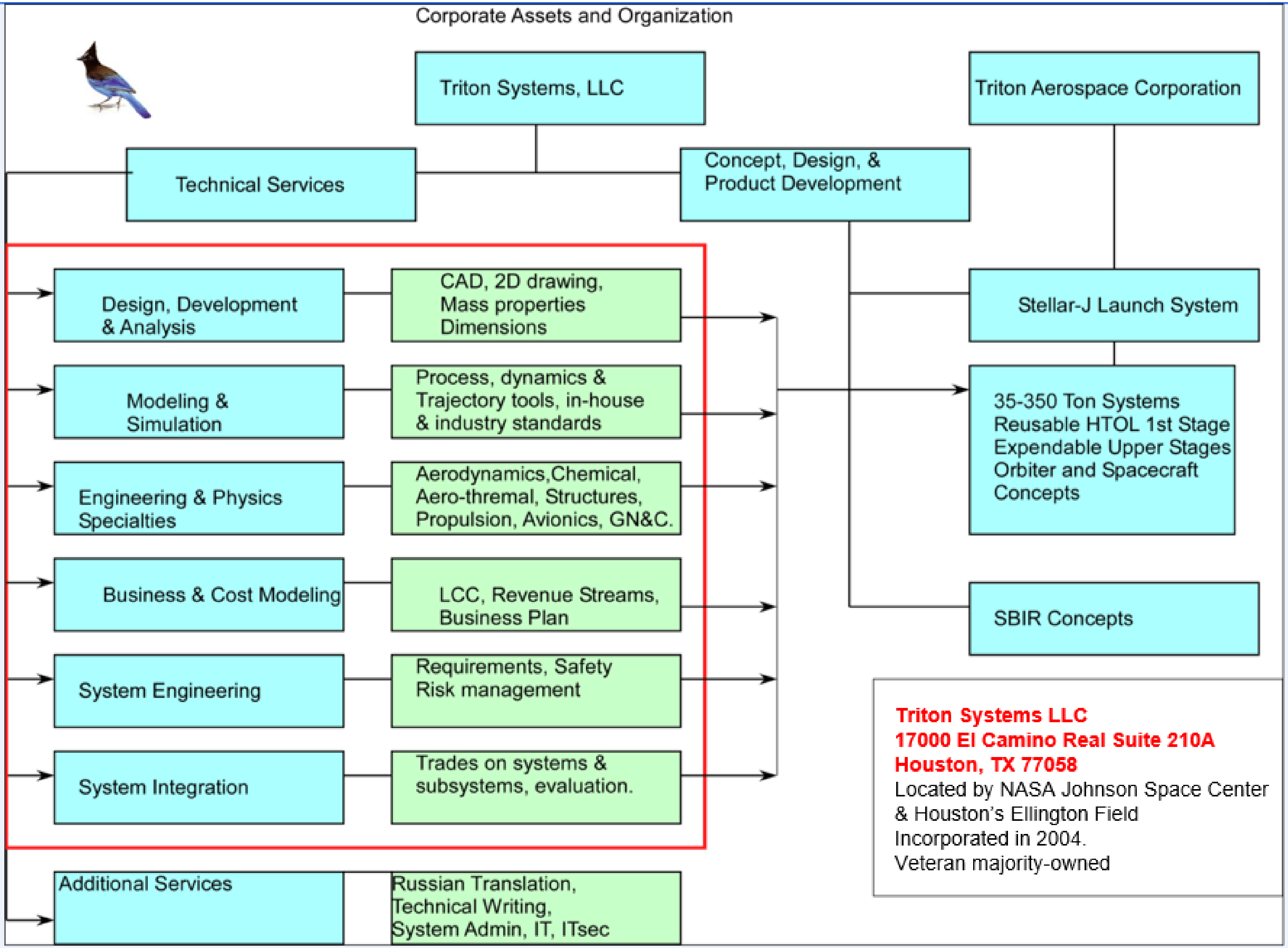
For the segments of Spars & Ribs,
Loads we will refer to generally as $P_{1,}$ P_2, P_3,..

Forces applied at specific spar or rib points
Represented by “Singularity Functions” at point “a”

Uniform loads begin at “a” and end at “b”

Same true of ramped and other functions.

In force, moment & deflection equations,
Integrated & differentiated as implied.


Corporate Assets and Organization
Triton Systems, LLC
Triton Aerospace Corporation
Technical Services
Concept, Design, & Product Development
Design, Development & Analysis
CAD, 2D drawing, Mass properties Dimensions
Modeling & Simulation
Process, dynamics & Trajectory tools, in-house & industry standards
Engineering & Physics Specialties
Aerodynamics,Chemical, Aero-thremal, Structures, Propulsion, Avionics, GN&C.
Business & Cost Modeling
LCC, Revenue Streams, Business Plan
System Engineering
Requirements, Safety Risk management
System Integration
Trades on systems & subsystems, evaluation.
Additional Services
Russian Translation, Technical Writing, System Admin, IT, ITsec
Stellar-J Launch System
35-350 Ton Systems
Reusable HTOL 1st Stage
Expendable Upper Stages
Orbiter and Spacecraft Concepts
SBIR Concepts
Triton Systems LLC
17000 El Camino Real Suite 210A
Houston, TX 77058
Located by NASA Johnson Space Center & Houston's Ellington Field
Incorporated in 2004.
Veteran majority-owned


TRITON SYSTEMS, LLC

Introduction

On September 4, 2013 in an auditorium adjacent to the NASA JSC,
The directors of Houston Airports , Rice University's Space Institute   and
6 former astronauts representing commercial space firms
Met to speak with the public about space enterprise.

"Rice Space Institute, Houston Airports,
Bay Area Houston Economic Partnership (BAHEP),
Commercial Spaceflight Federation (CSF) and 5 Firms
Present Panel Discussion on Commercial Spaceflight and a Spaceport"

Ironically, it was one of the 6 astronaut speakers (Chris Ferguson)
Whose duty it was to call in the last report from a Space Shuttle flight deck:
"Houston, wheels locked." after Shuttle Atlantis mission STS-135 landed at
KSC on 21 July 2011.

Yet despite the retirement of the Space Shuttle, the director of the
Houston Airport System chose this evening to promote Elliington Field,
Houston's "3rd Airport" as a Spaceport.

**Mr. Diaz, in assessed the current commercial space industry as
a $256 billion global enterprise with a growth rate ~5% annually.**

And despite the gathering of space businesses,
None addressed operations at Houston-Ellington
Nor the most accessible services, identifiable customers or markets!

WE WILL.

NOTES

Development Snap Shot

- As the Design Matures, Useful Engineering Textbooks Include…
- Other Areas Not Well Documented (Ascent Trajectories, Especially Air-breathing)
- Delta Wings (more and more cantilever and intersecting spars and ribs) though structures books abound.
- Current Effort Defining Aircraft Dynamics & Control through Major Modes

History HTOL Launch and Related Matters – from Our Perspective

- Due to my age, I discovered spaceflight before Star Wars..
  Captain Video, Tom Corbett – Space Cadet, Sputnik and Robert Heinlein…

Why Do This and What Do Customers Want?

Consider Professor Van Allen of Iowa State Pioneer of Spacefligtt with Explorer I

To read his opinion pieces, the only reason to build a rocket is to study magnetospheres…

At the other extreme are friends and colleagues of Elon Musk, they are preparing to settle Mars.

Analysis Topics

-Trajectories with and without Wings

-Performance Analysis

- Jet engines, wings, effective ISP and the removal of DV (principally work) from the rocket equation

-Reusable Systems, especially propulsion (do or can they pay for themselves)

- Lessons or data from previous programs (Shuttle and its derivatives – Liquid Booster Engines, aero, conventions)
- The X-34, the little reusable that never flew.

-