Aircraft Design Class

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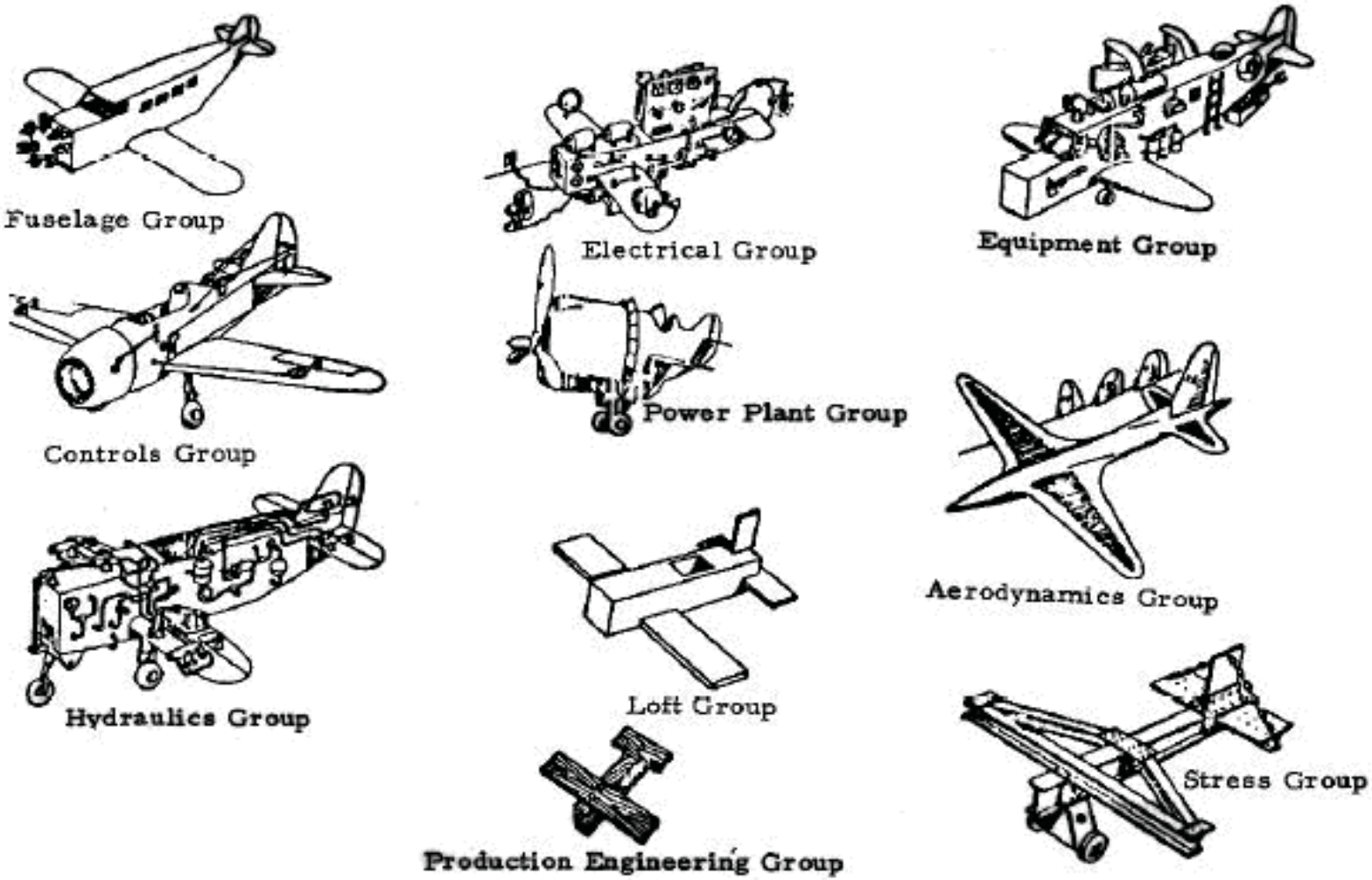
Beauty is in the Eye of the Beholder

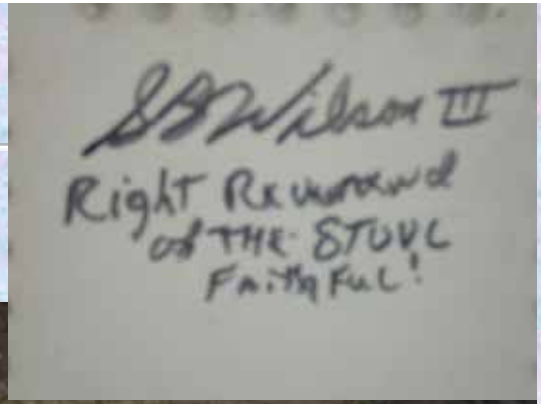


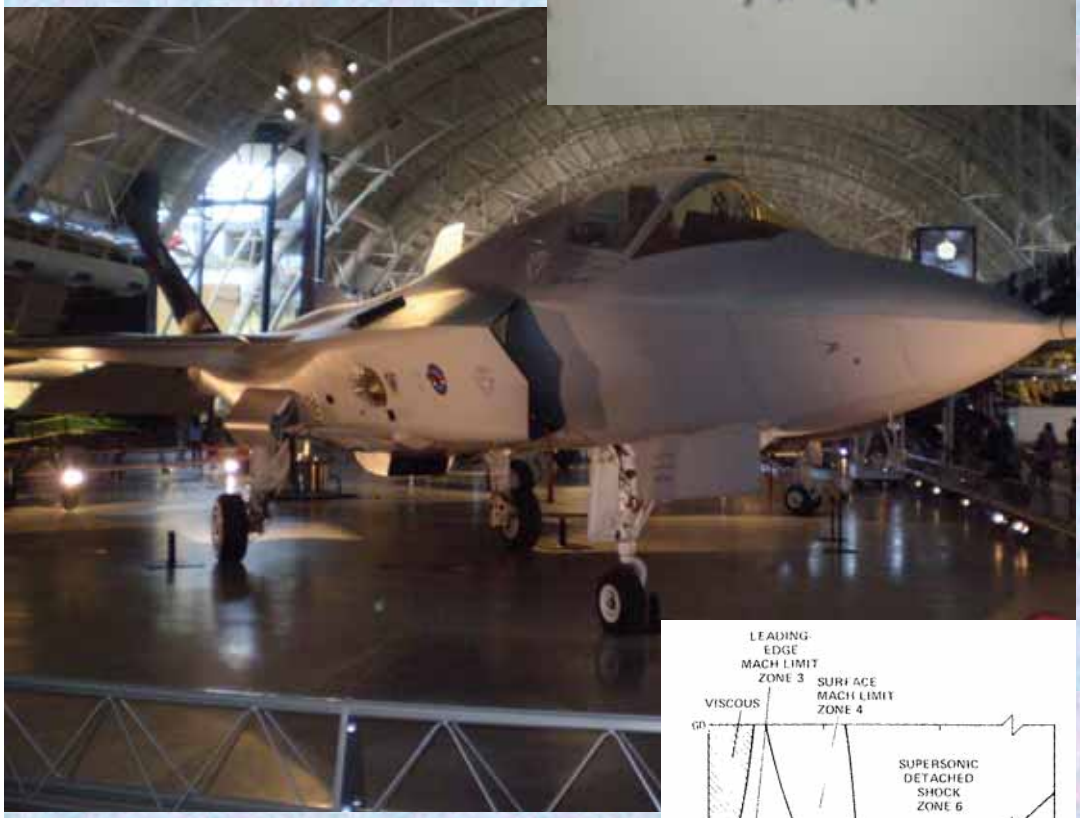
"Dream Airplanes" by C.W. Miller,
as shown in *Fundamentals of Aircraft Design*, by L.M. Nicolai

Design Methods

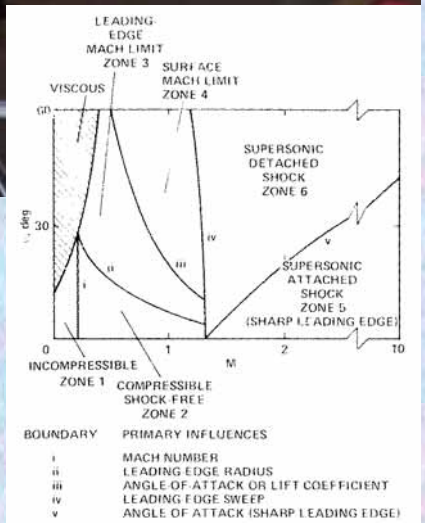
What Size?

What Shape?

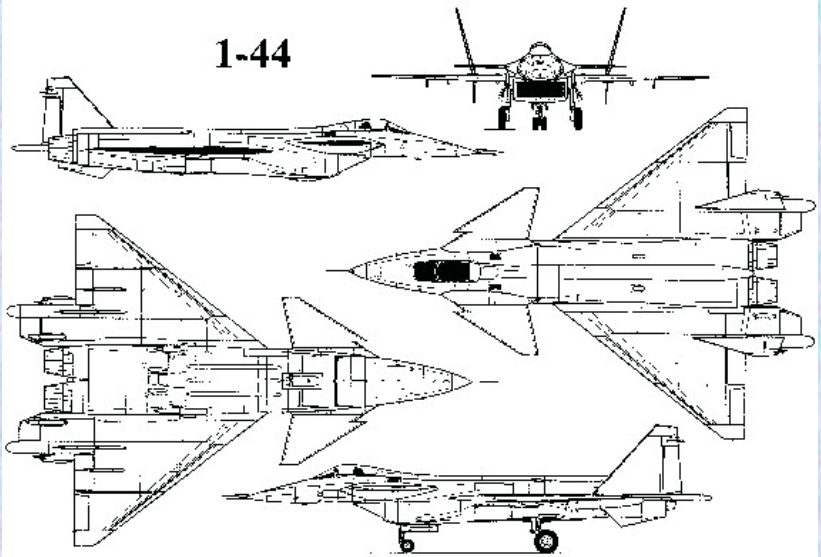




JSF X-35B



Design "As Drawn"



- Computer evaluation of Conceptual Designs
- "As Drawn" Assumes fixed external mold-lines
- Weight as independent variable - "loop closure"

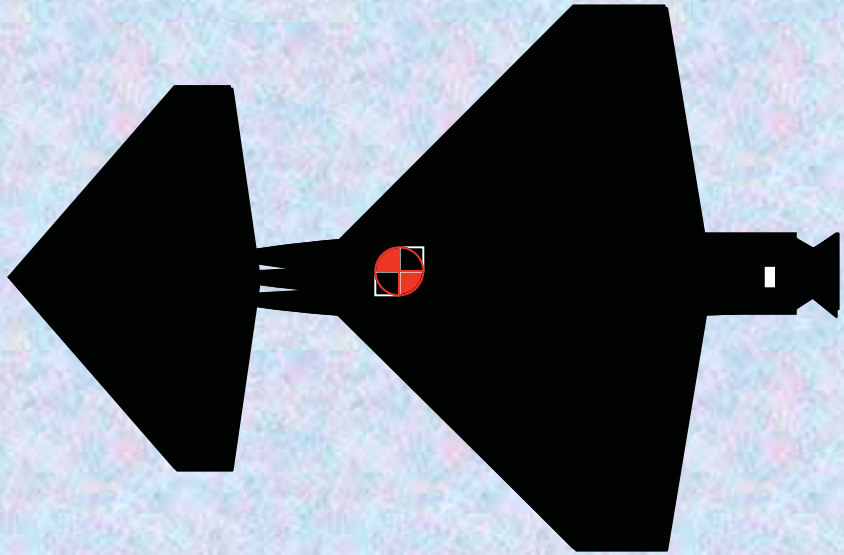
Integration Challenge:

- To design a supersonic fighter/attack aircraft that offers the operational flexibility of Short Takeoff and Vertical Landing (STOVL)
- Need to make the same design compromises as a conventional fighter, plus one: use the available thrust in a manner that allows a controlled vertical landing
- This single added constraint requires a more systematic approach to the design of an aircraft.

V/STOL Aircraft Design Process

Step 1

- Define wing & horizontal stabilizer geometry
- Located engine "vertical thrust" center with respect to aerodynamic center

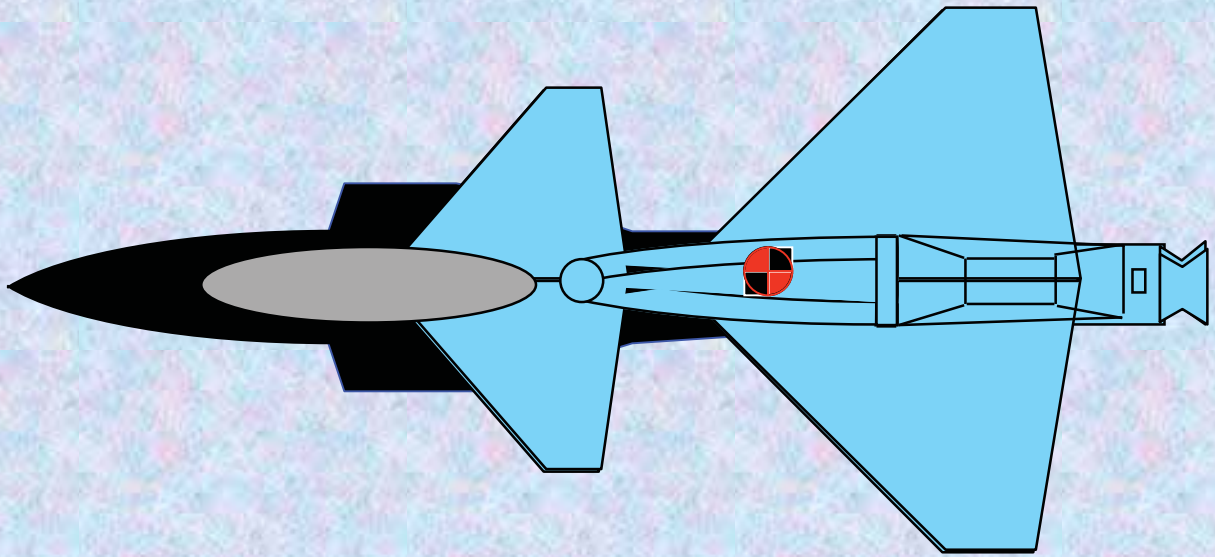


Ref NASA CR-177437

V/STOL Aircraft Design Process

Step 2

- Add minimum length inlet/diffuser
- Add cockpit and forebody

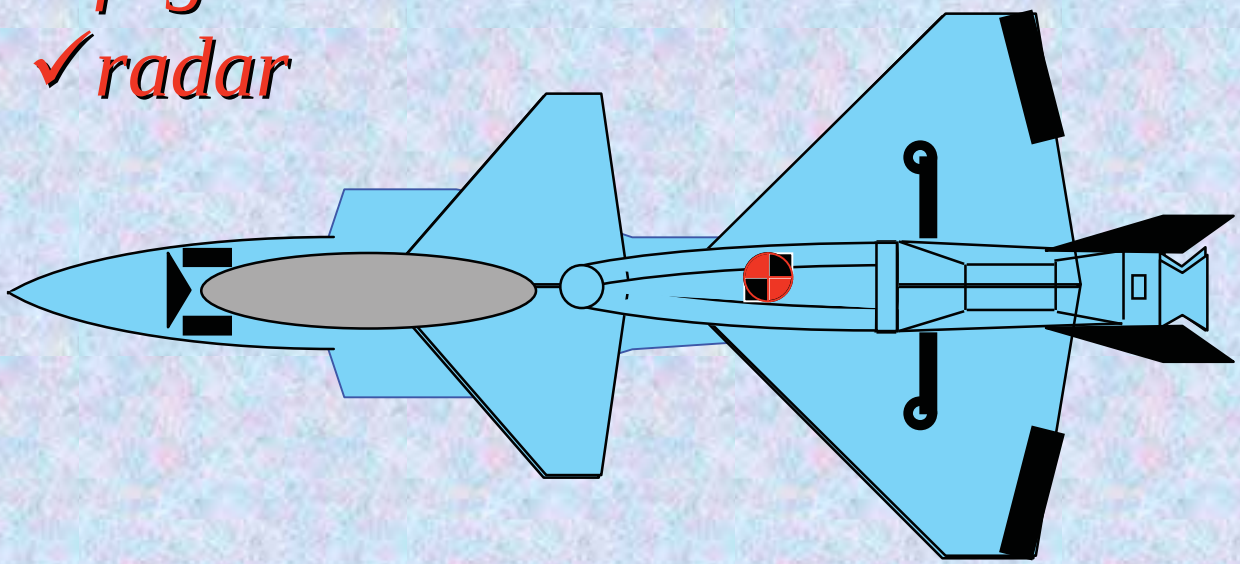


Ref NASA CR-177437

V/STOL Aircraft Design Process

Step 3

- Add vertical tails
- Assign location dependent masses
  - *landing gear*
  - *flight controls*
  - *radar*

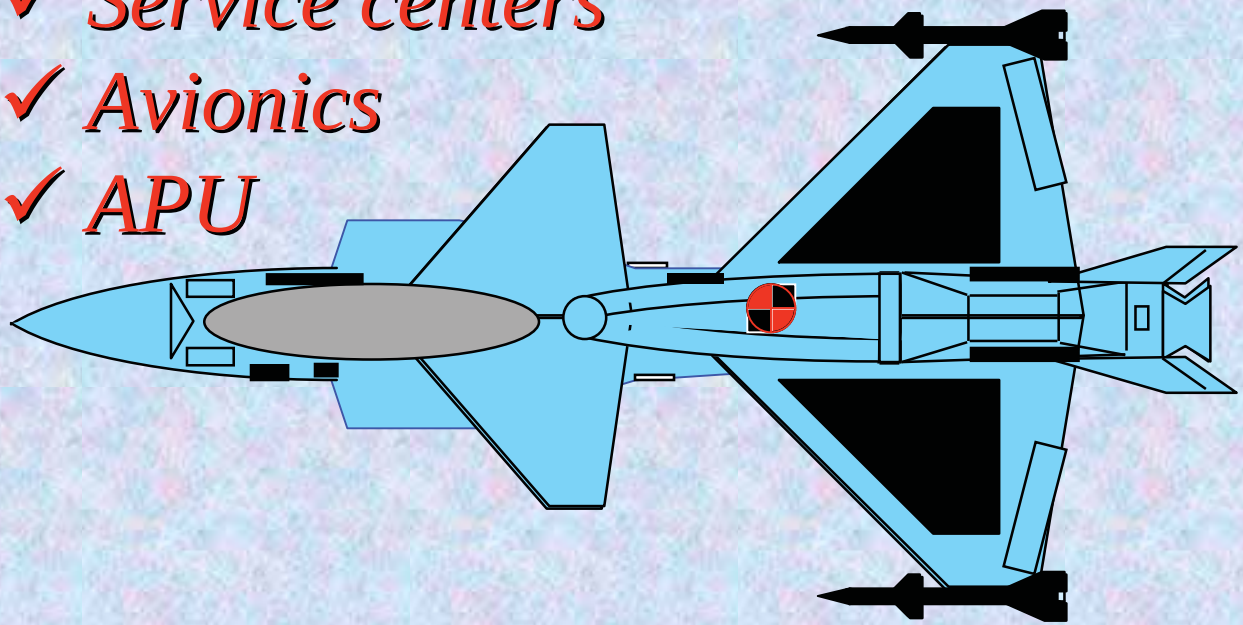


Ref NASA CR-177437

V/STOL Aircraft Design Process

Step 4

- Add Payload bays / weapon hardpoints
- Add fuel tanks
- Assign location independent masses
  - ✓ *Service centers*
  - ✓ *Avionics*
  - ✓ *APU*

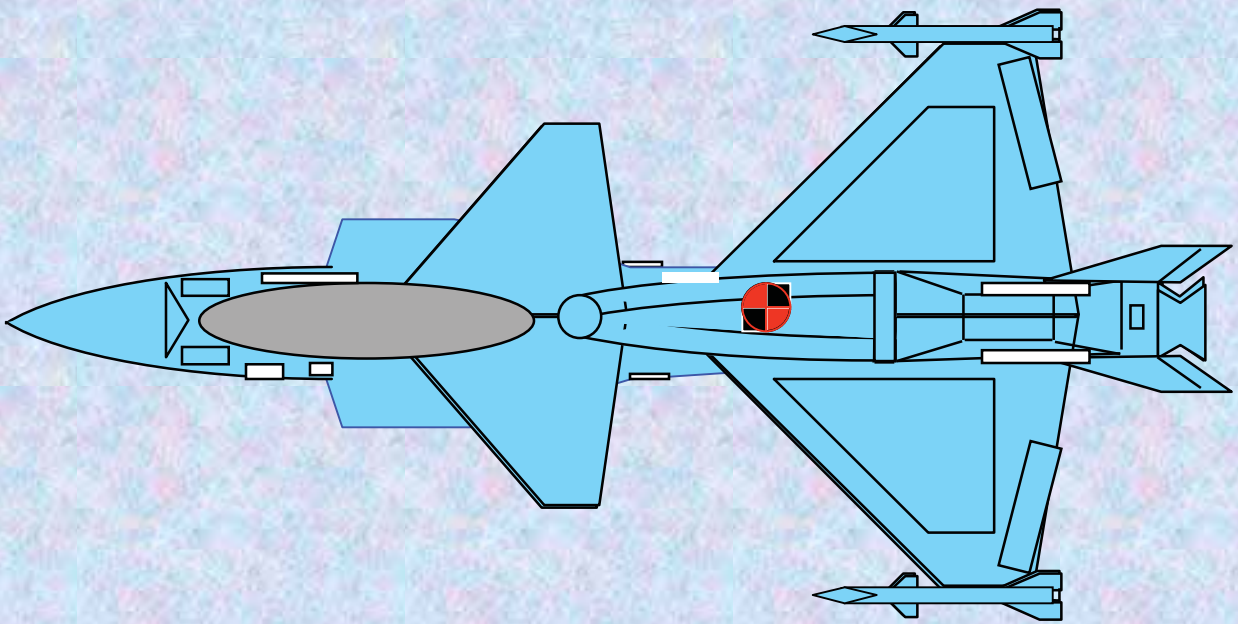


Ref NASA CR-177437

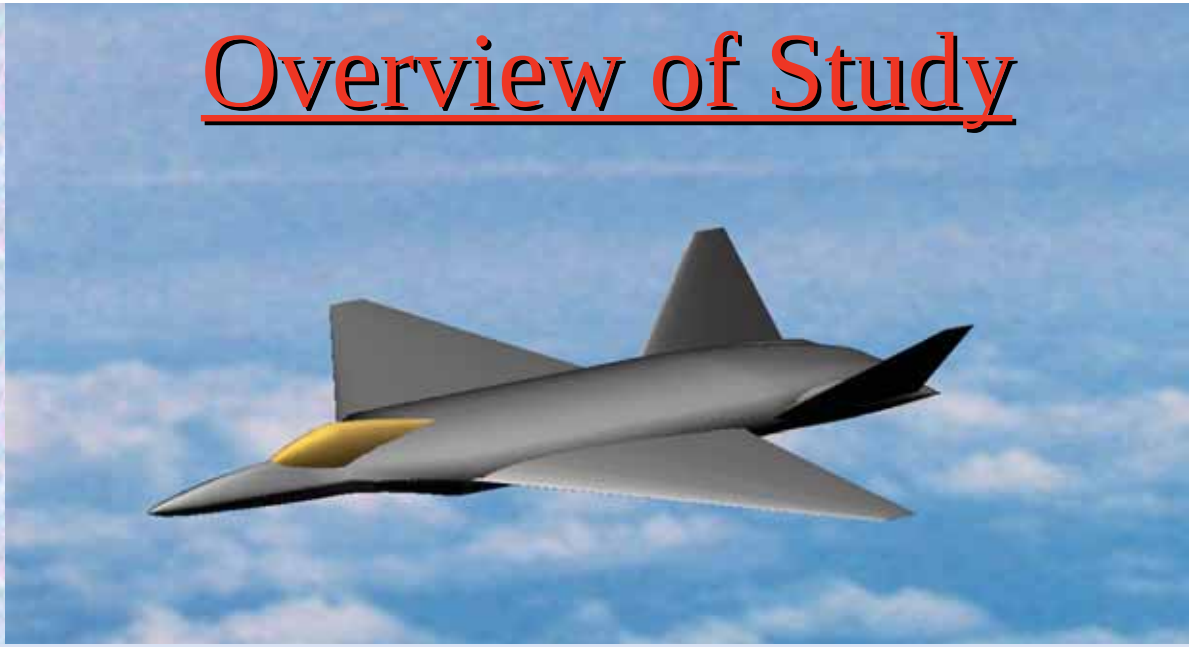
V/STOL Aircraft Design Process

Step 5

- **Add lead weight ballast!**
  - ✓ *CG too far forward*
  - ✓ *Vertical thrust center too far aft*



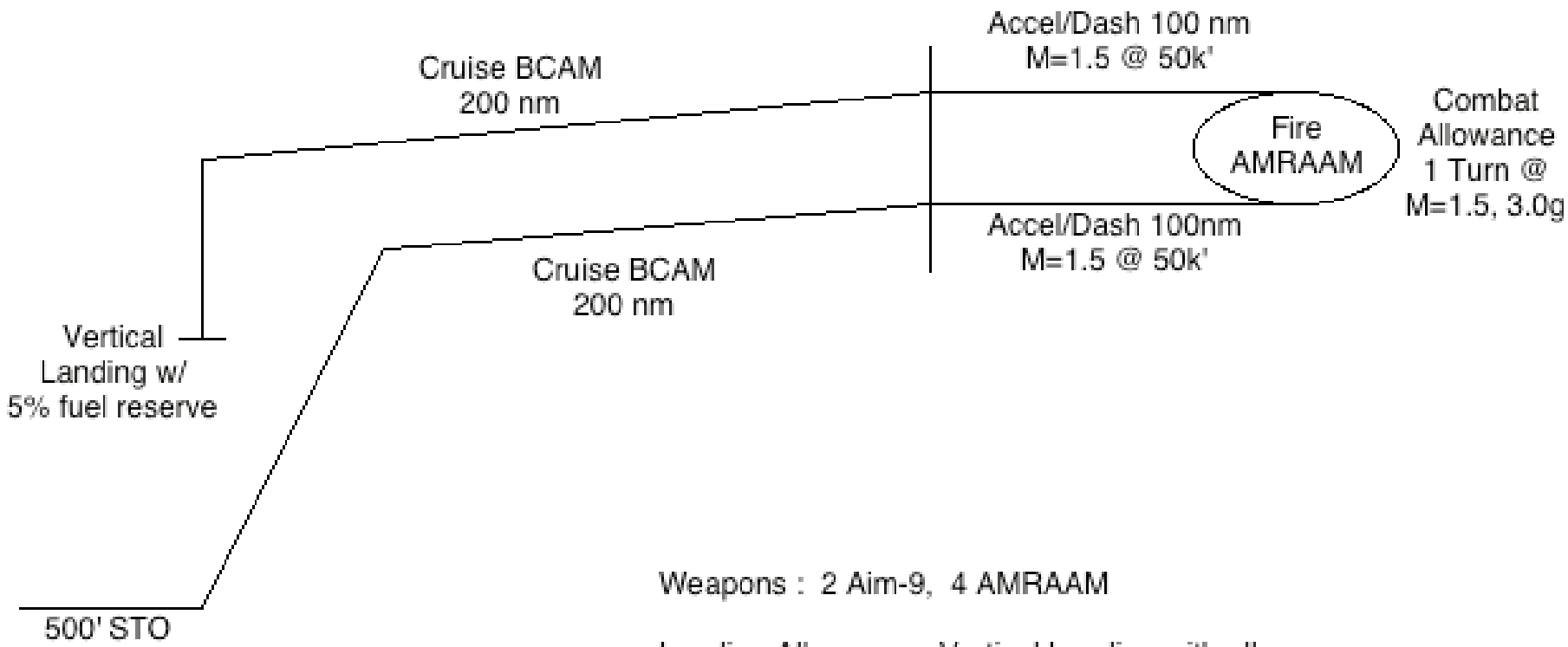
Overview of Study



- Description of four candidate propulsion systems which can be based on a single gas generator
- First order effects of the four propulsion systems on the sizing of a STOVL fighter

Design Mission

Design Mission



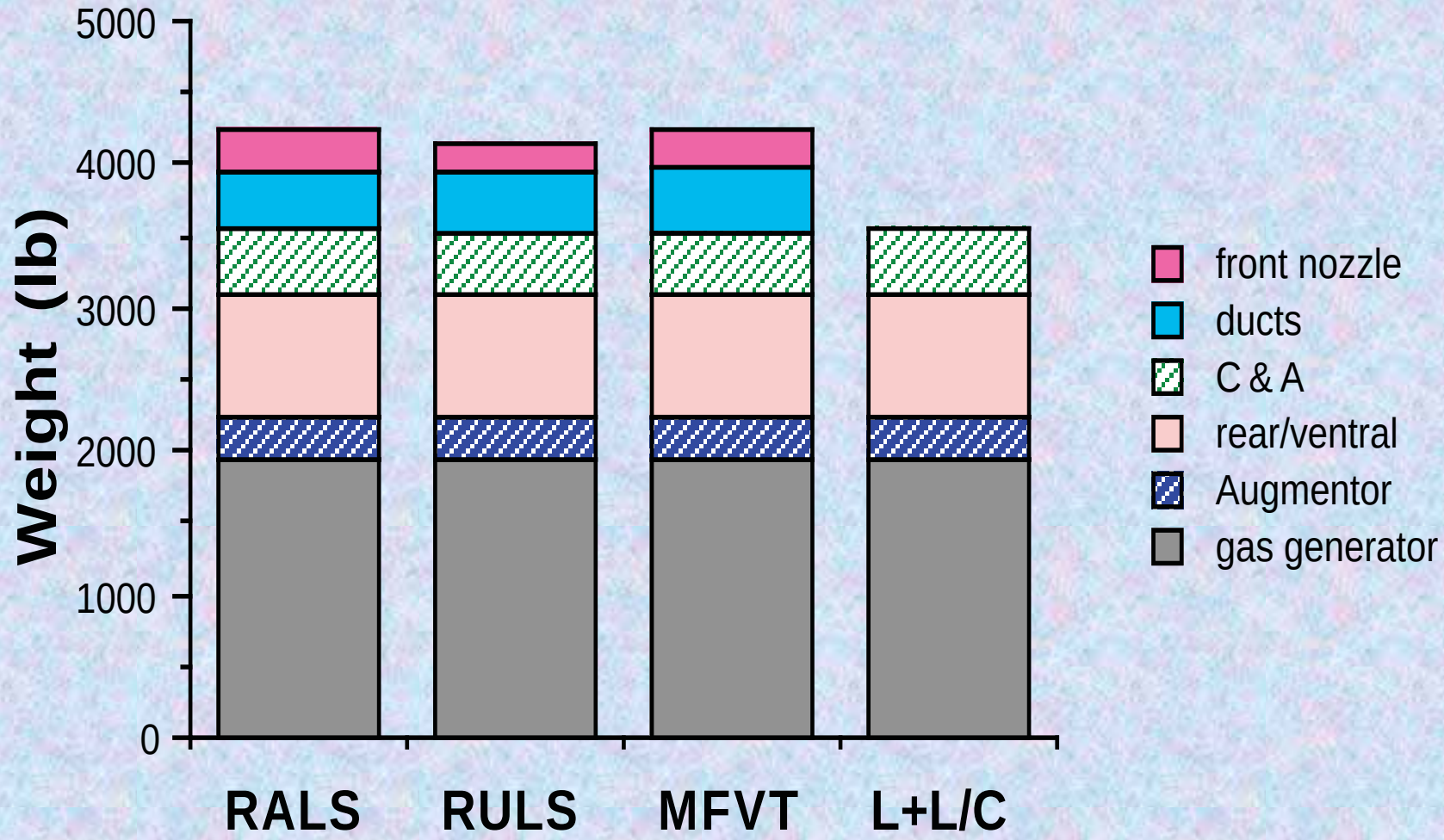
Weapons : 2 Aim-9, 4 AMRAAM

Landing Allowance: Vertical Landing with all weapons and 10% fuel

Design Manuver Point: M=0.90, alt=30k', Nz=4.5g

STOVL Lift Systems Study

- Unscaled Propulsion System Weights



Thrust to Weight Definitions (review)

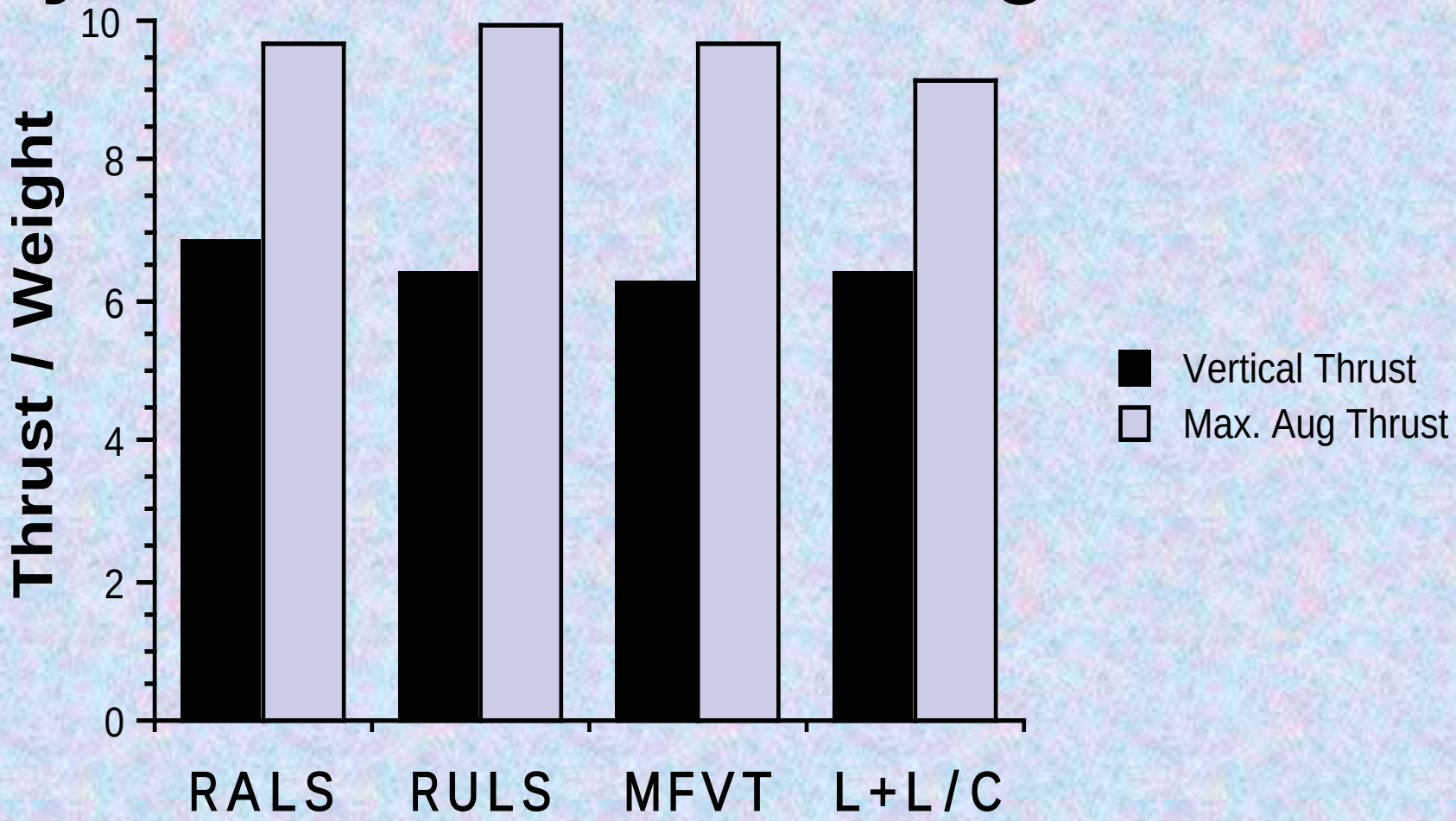
$$\text{Engine T/W} = \frac{\text{Uninstalled Max A/B Thrust}}{\text{CTOL Engine Weight}}$$

$$\text{System T/W} = \frac{\text{Installed Max A/B Thrust}}{\text{Total Propulsion System Weight}}$$

$$\text{Lift System T/W} = \frac{\text{Balanced Vertical Thrust}}{\text{Total Propulsion System Weight}}$$

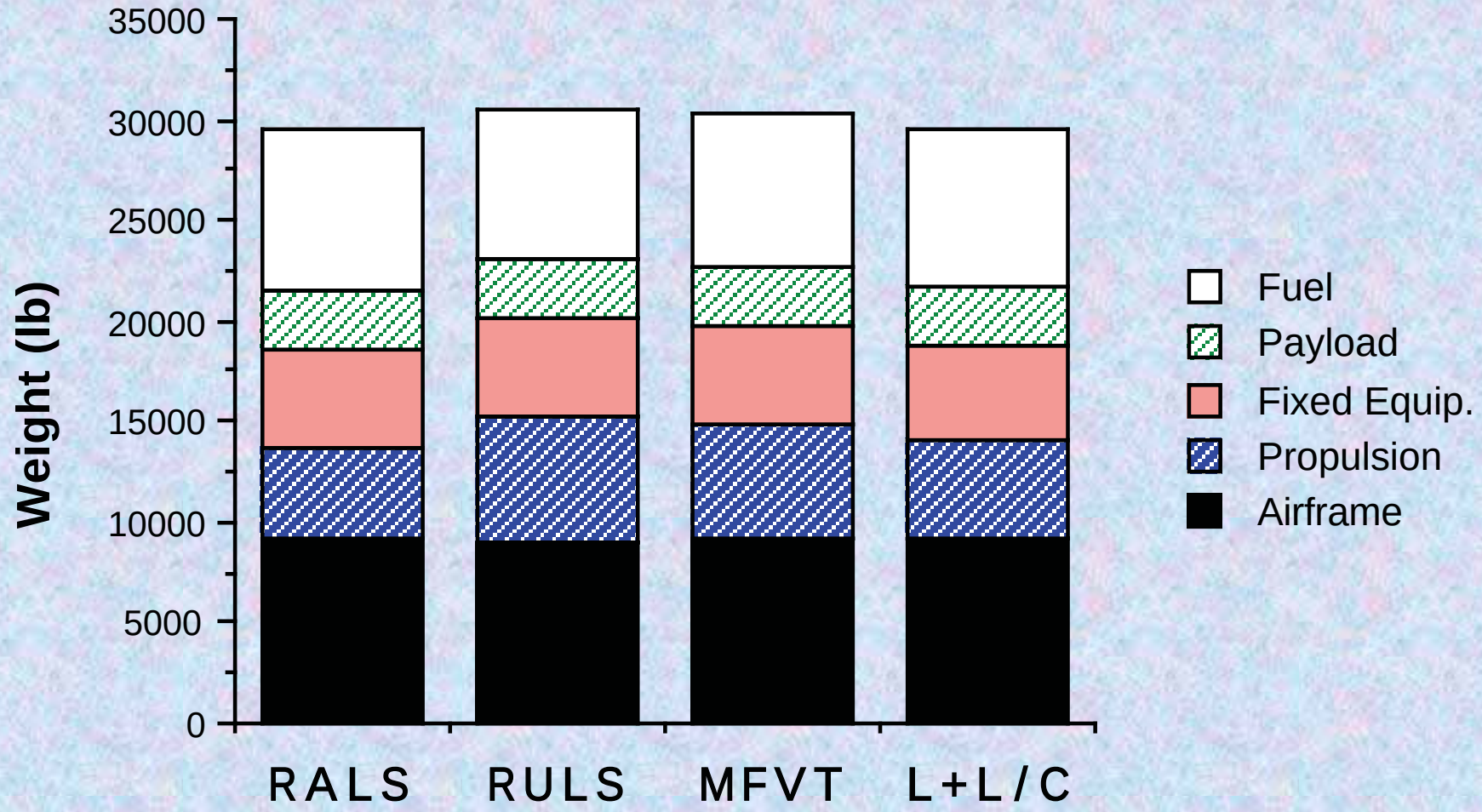
STOVL Lift System Performance

System Thrust to Weight



STOVL Lift System Breakout

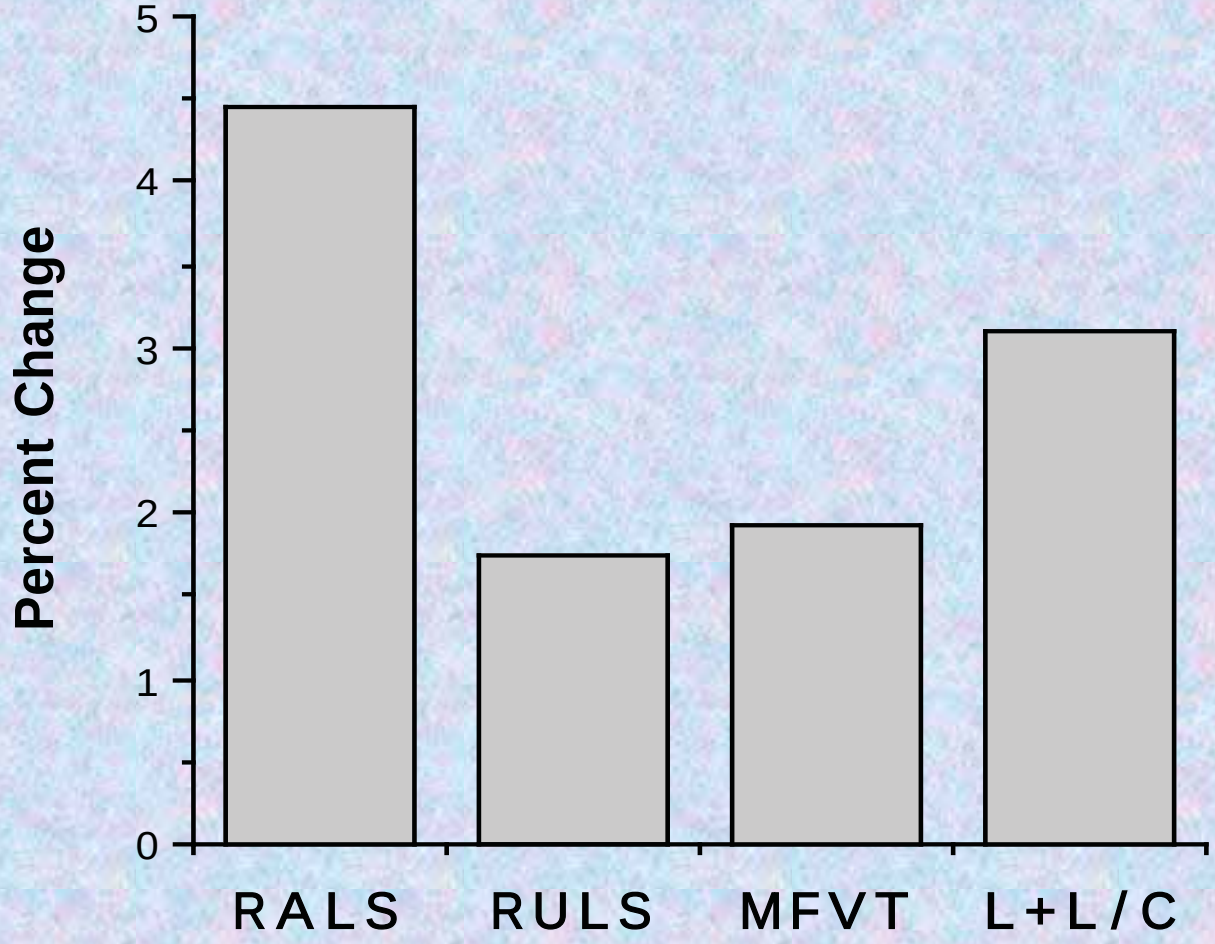
Group Weights



STOVL Gross Weight Sensitivity

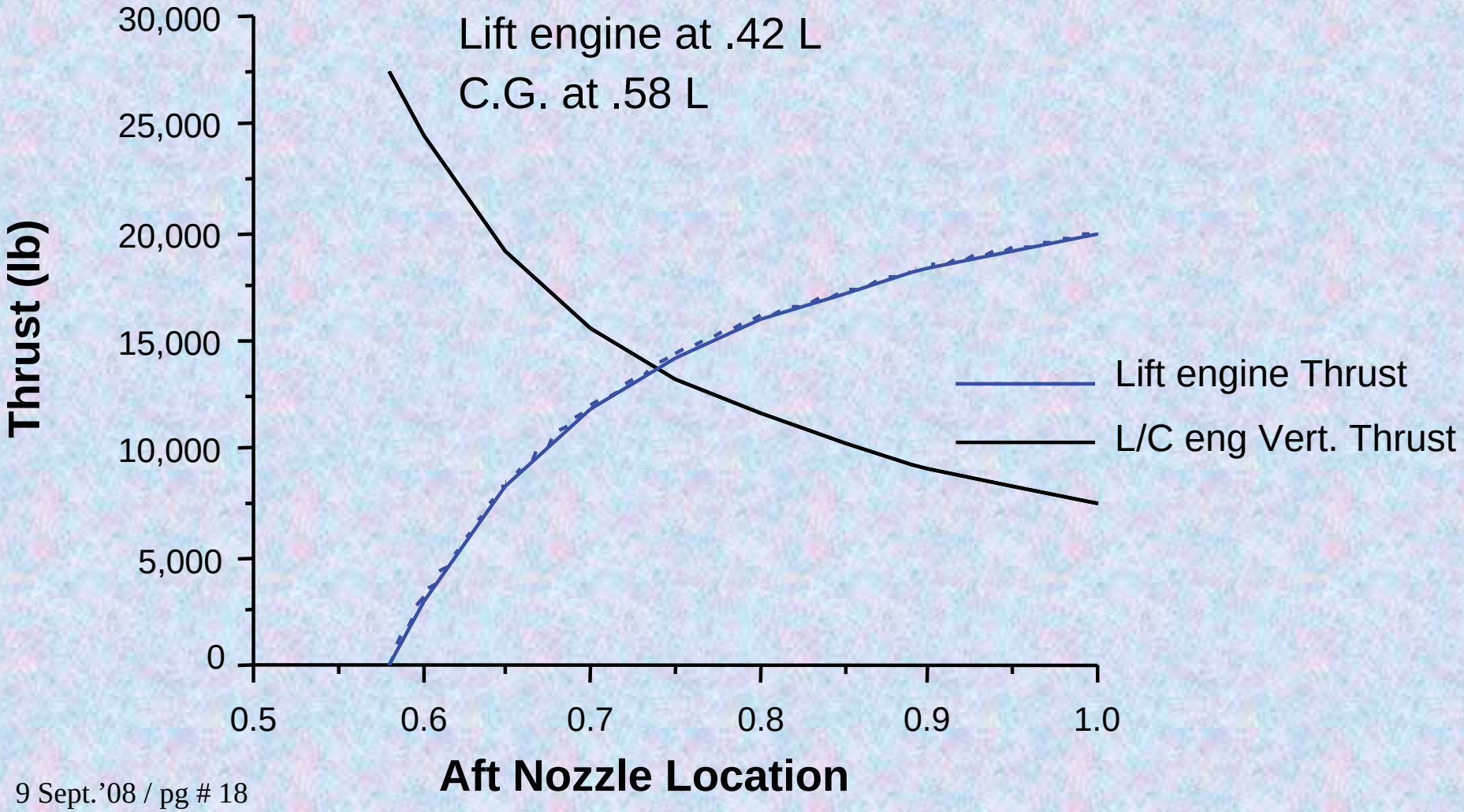
- **Design Point Sensitivity**

10% change in manuver performance

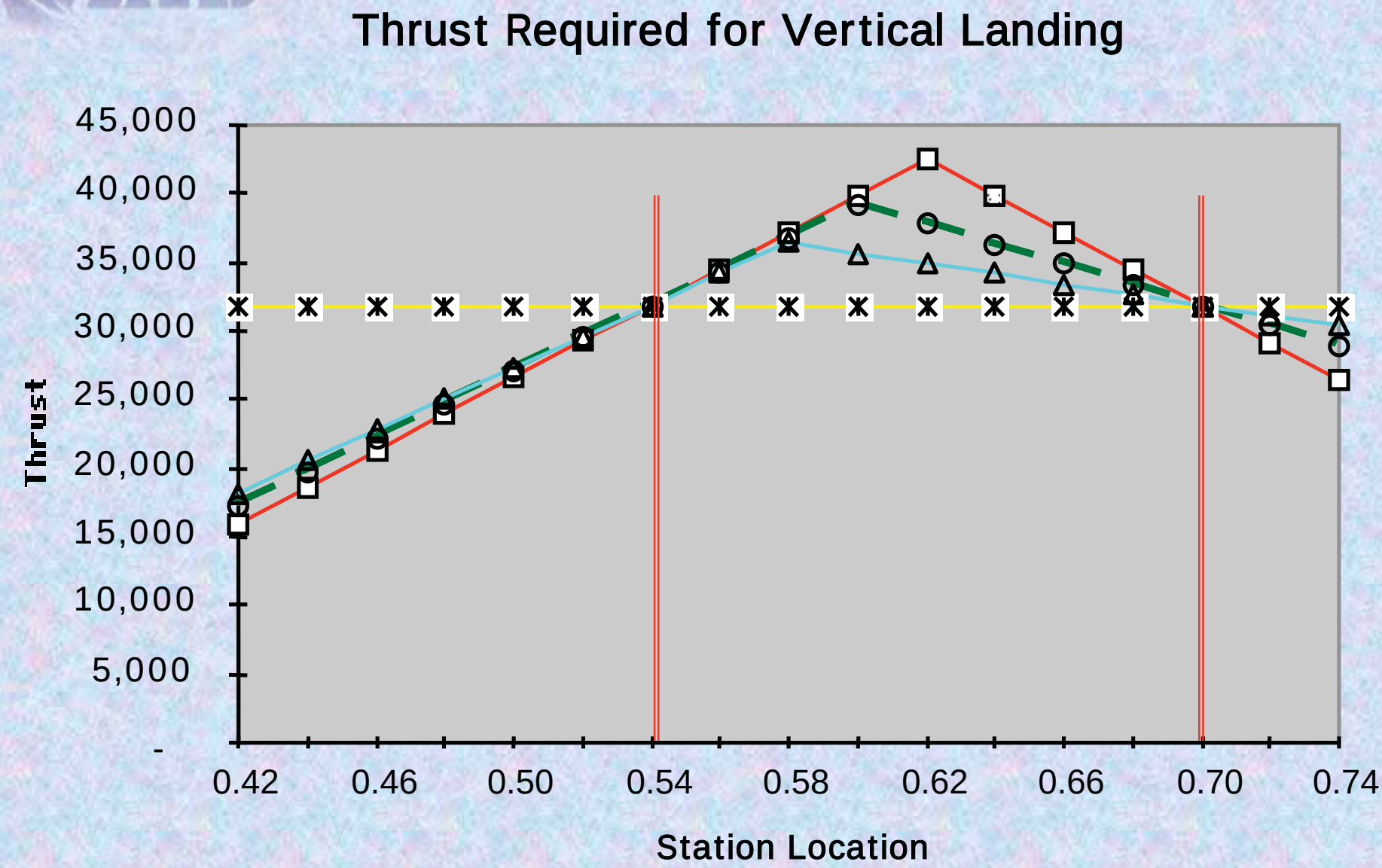


Cruise Engine Thrust for L+L/C

Thrust Distribution



Hover Balance



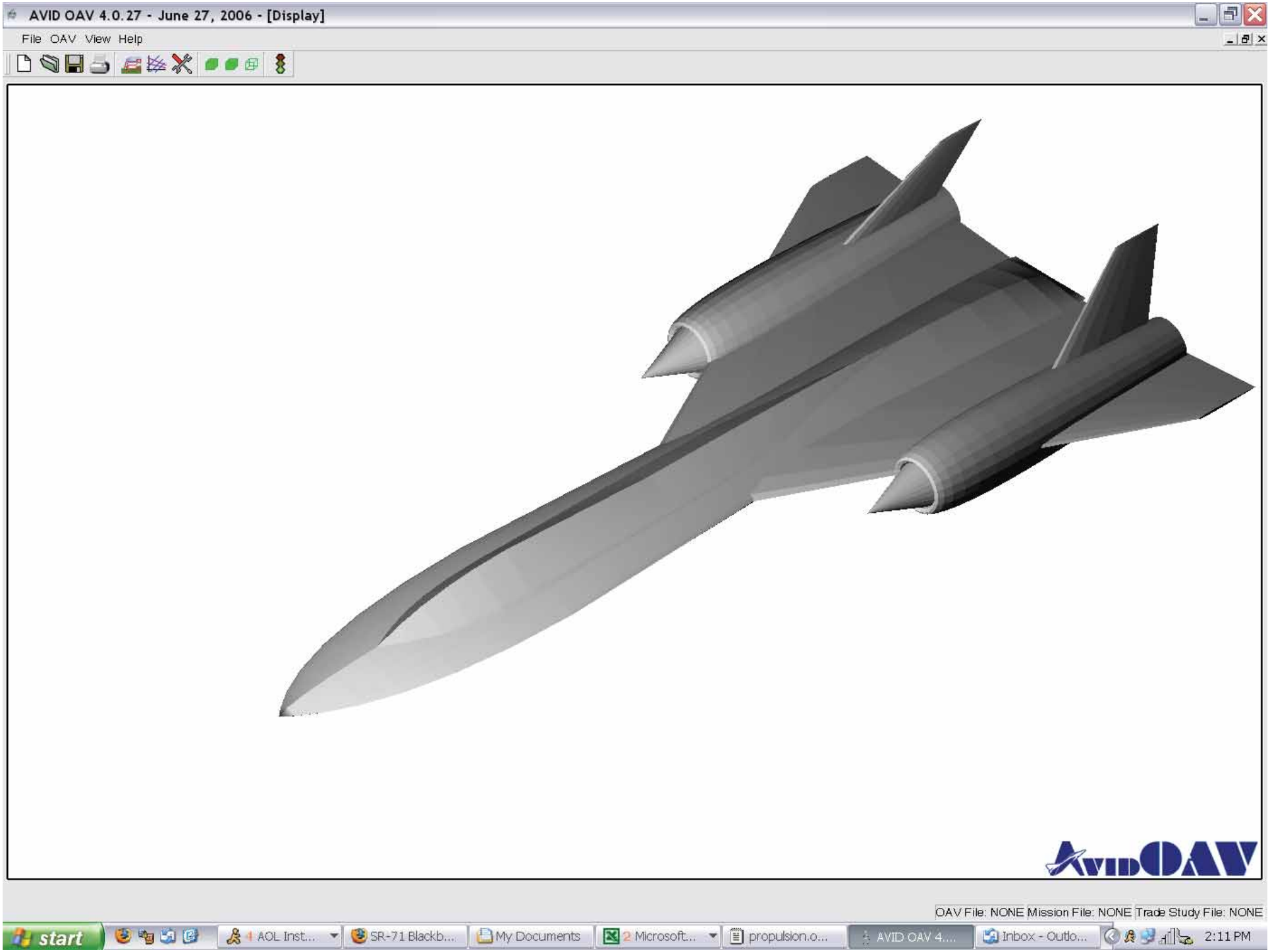
Off Design Performance

Fallout Performance

	RALS	RULS	MFVT	L+L/C
Ps @ M=1.50, 30k'	410	1123	861	583
Nz @ M=0.60, 20k'	4.05	4.04	4.03	4.05
Nz @ M=1.20, 40k'	3.14	3.77	3.59	3.34

Conclusion for Lift Engines

- If high maneuver performance and/or dry super-cruise is required, lift engines have limited value (mission dependent)
- Lift System thrust to weight is not a strong function of engine T/W for many engine configurations
- Factors other than mission performance will be necessary to choose a propulsion system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CNA Air Panel Study

- *Tactical Air Assets for Carrier Task Force*
  - *Fighter & Attack Aircraft vs. Multi-Mission Aircraft*
  - *STOVL vs. Conventional Carrier Based Aircraft*
  - *No Utility Aircraft Assessments*
- *Used STOVL Strike Fighter TOR Missions*
  - *Latest Statement of Future Naval Mission Requirement*
  - *Multi-Mission (F/A & SSF) Do All Missions*
  - *Subsonic Attack Aircraft Point Designed for Air to Ground*
  - *"Blue Water" Fighter Optimized for Fleed Air Defense*
- *Emphasis on Time Based Technology Trends*
  - *Baseline was US/UK ASTOVL "1995 TAD" Assumptions*
  - *“1990 TAD” Timeframe Allows for "What is Available"*

NASA-Ames Study Plan

Technology Availability Date

- Common: Engine Cycle, Weapons, Avionics, etc.

	1990-TAD	1995-TAD
Radar Absorbing Material	+ 0%	+ 5%
Internal Weapons Carriage	No	Yes
1.5M Supersonic Cruise	A/B	"Dry"
Design Load Factor	7.5	9.0
Technology Factor	90%	85%
Propulsion System T/W	~12	~15

Differentiators

"1990 TAD" Aircraft Class

	Fighter	Multi-Mission	Attack
✈Structural Tech. Factor	-10%	-10 %	-10%
✈Design Load Factor	6.5 g	7.5 g	6.5 g
✈Survivability Impacts	No	No	No
✈Dry Super-cruise	No	No	No
✈Plan form	Variable	Standard	Standard
✈Wing Pivot	+30%	0	0
✈Tail Surfaces	Standard	Standard	Standard

Differentiators

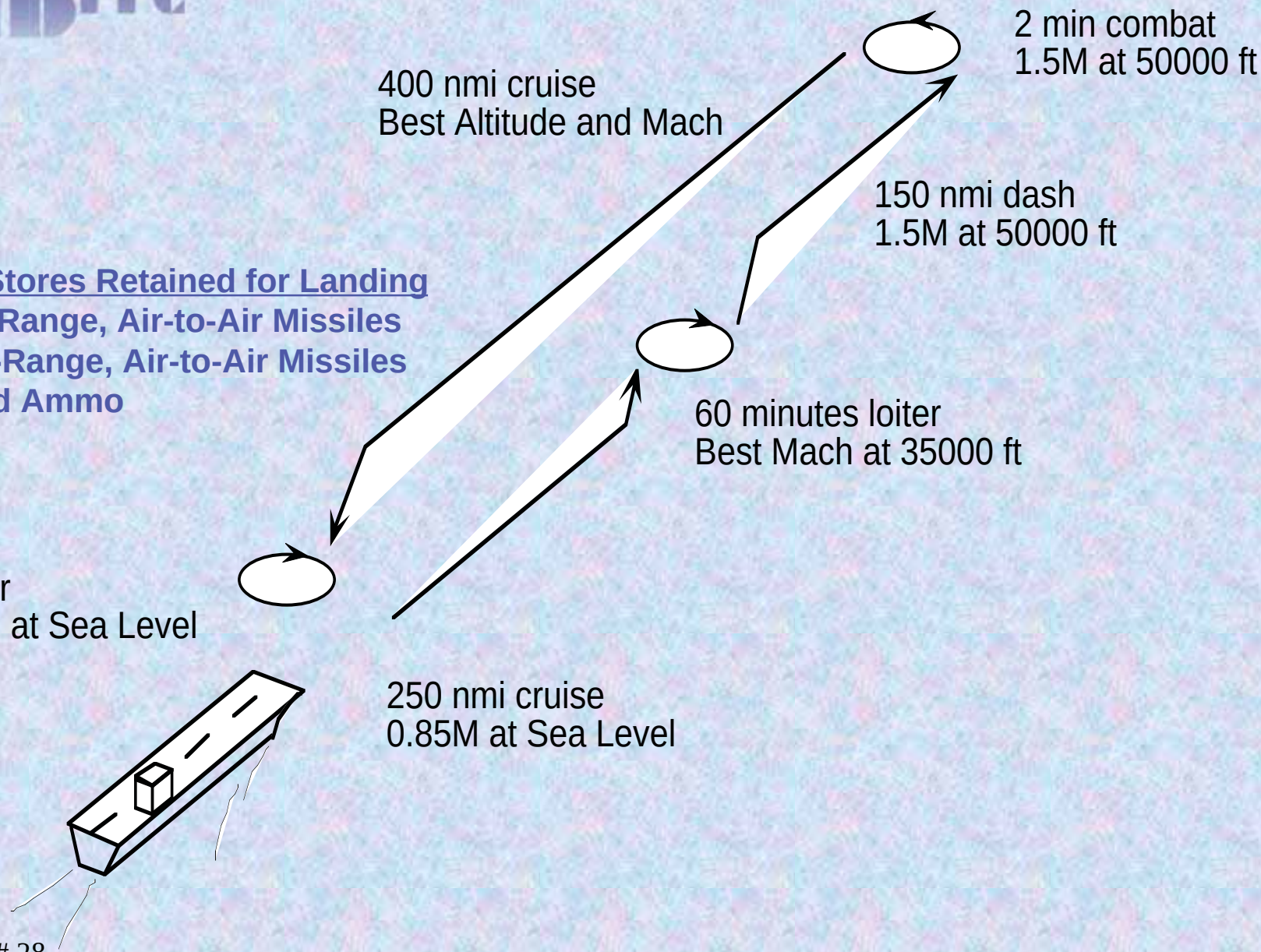
"1995 TAD" Aircraft Class

	Fighter	Multi-Mission	Attack
✈Structural Factor	-15%	-15 %	-15%
✈Design Load Factor	9.0 g	9.0 g	6.5 g
✈Survivability Impacts	No	Yes	Yes
✈Dry Supercruis	Yes	Yes	No
✈Planform	Variable	Diamond	Flying Wing
✈Wing Pivot	+30%	0	0
✈Tail Surfaces	Conventional	Conventional	None

Ames CNA Study Description

- **Three Aircraft Classes**
  - ✓ **Direct-Lift STOVL**
  - ✓ **Sea-Based ("Cat / Trap")**
  - ✓ **Land-Based**
- **Two Technology Timeframes**
  - ✓ **1990-TAD**
  - ✓ **1995-TAD**
- **Philosophy**
  - ✓ **ACSYNT - Design Synthesis Code**

Baseline Design Mission



High Value Stores Retained for Landing

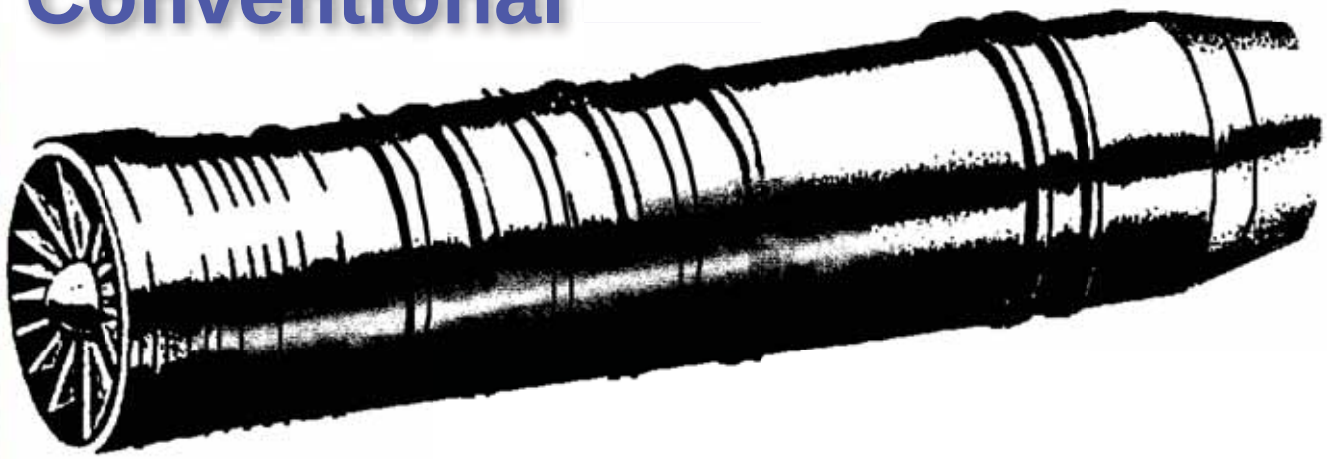
- **2 Long-Range, Air-to-Air Missiles**
- **2 Short-Range, Air-to-Air Missiles**
- **Gun and Ammo**

Aircraft Class Details

	STOVL	Sea-Based	Land-Based
Fuselage Structure	0	+ 30 %	0
Landing Gear Structure	0	+ 30 %	0
Carrier Approach	No	Yes	No
Propulsion Weight	+ 47%	0	0
Landing Hover T/W	1.16	N/A	N/A
Reaction Control System	Yes	No	No
Duct Volume Penalty	~10%	0	0
Loiter in Pattern	10 min	20 min	20 min

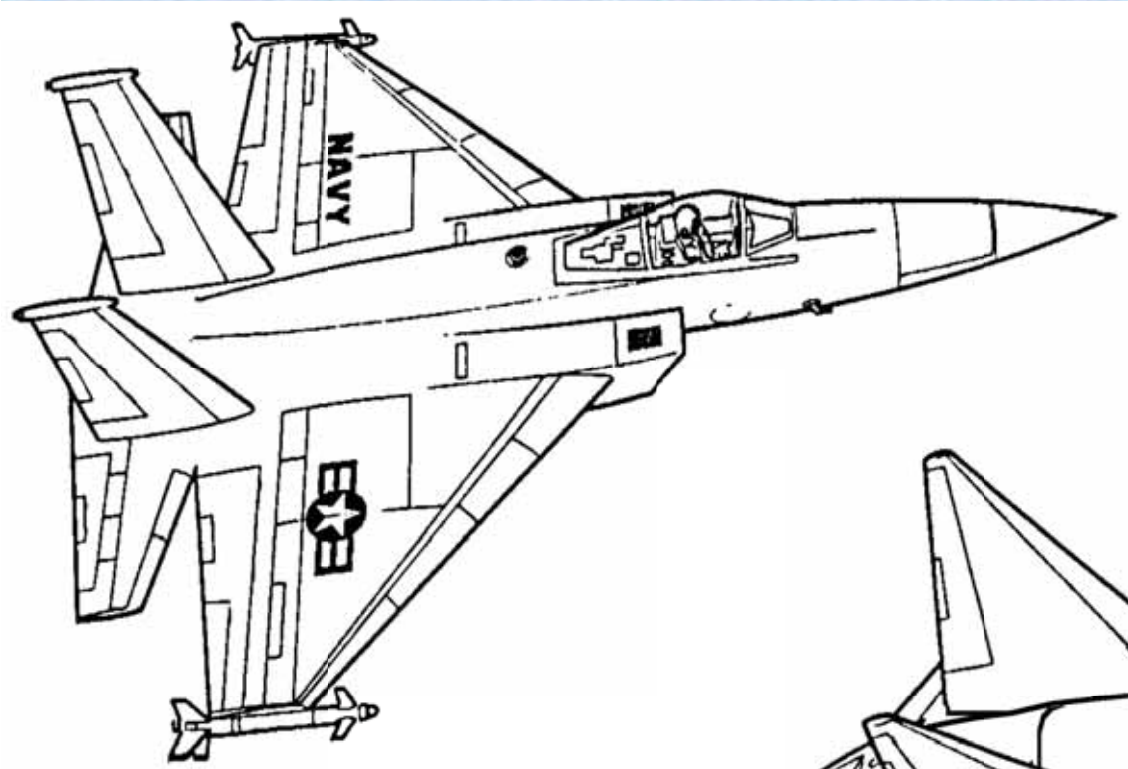
Propulsion Systems

Conventional

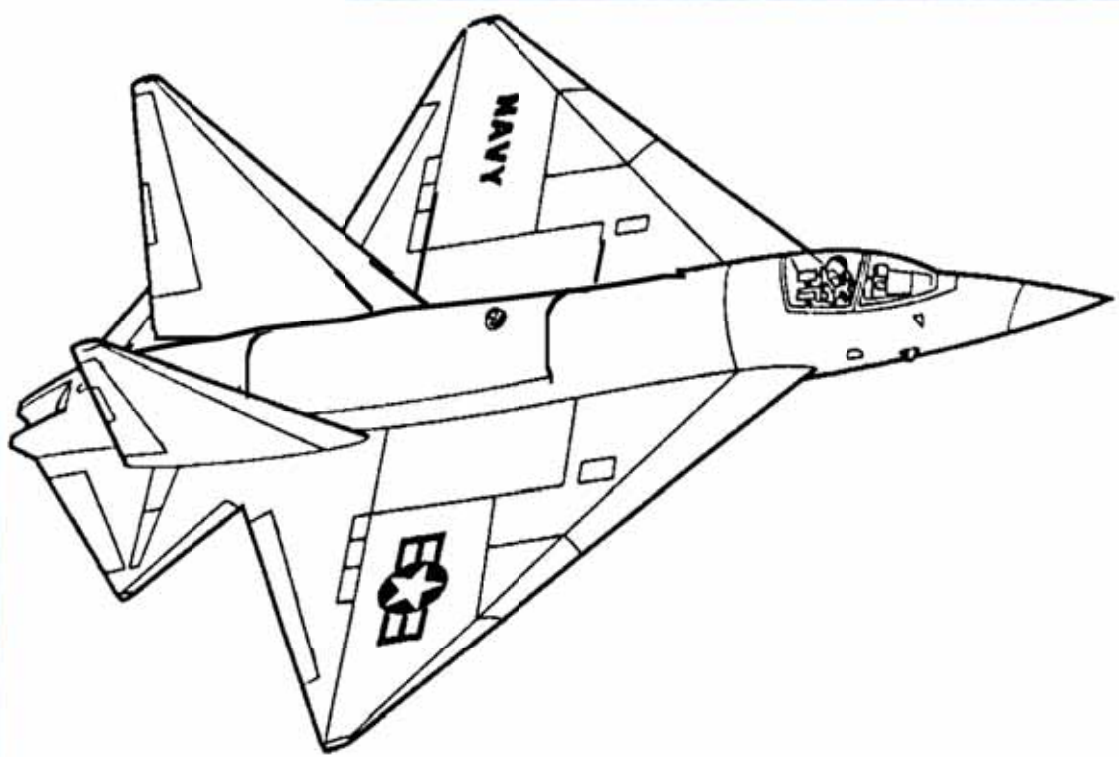


Direct-Lift STOVL

Aircraft Evolution

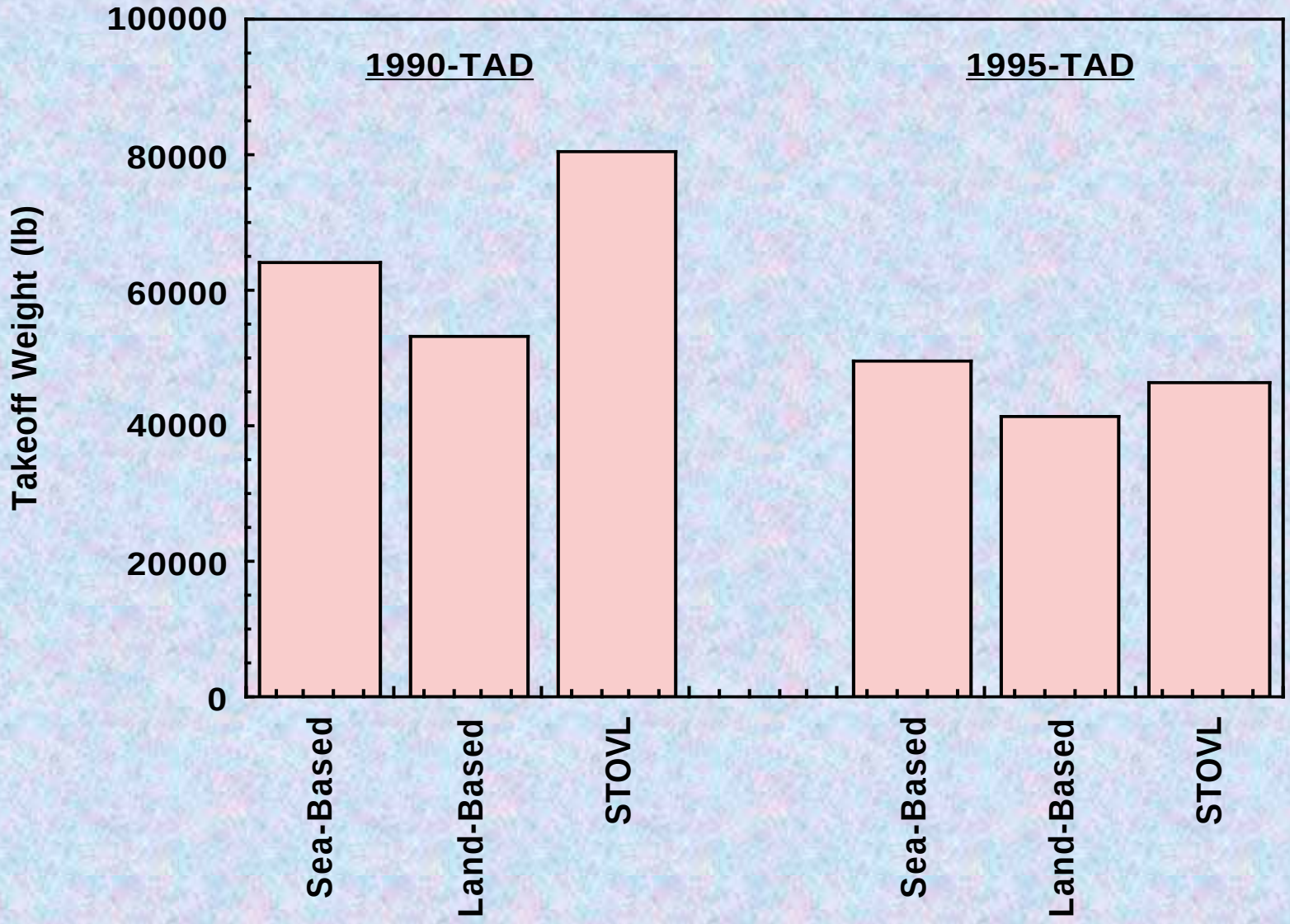


1995-TAD

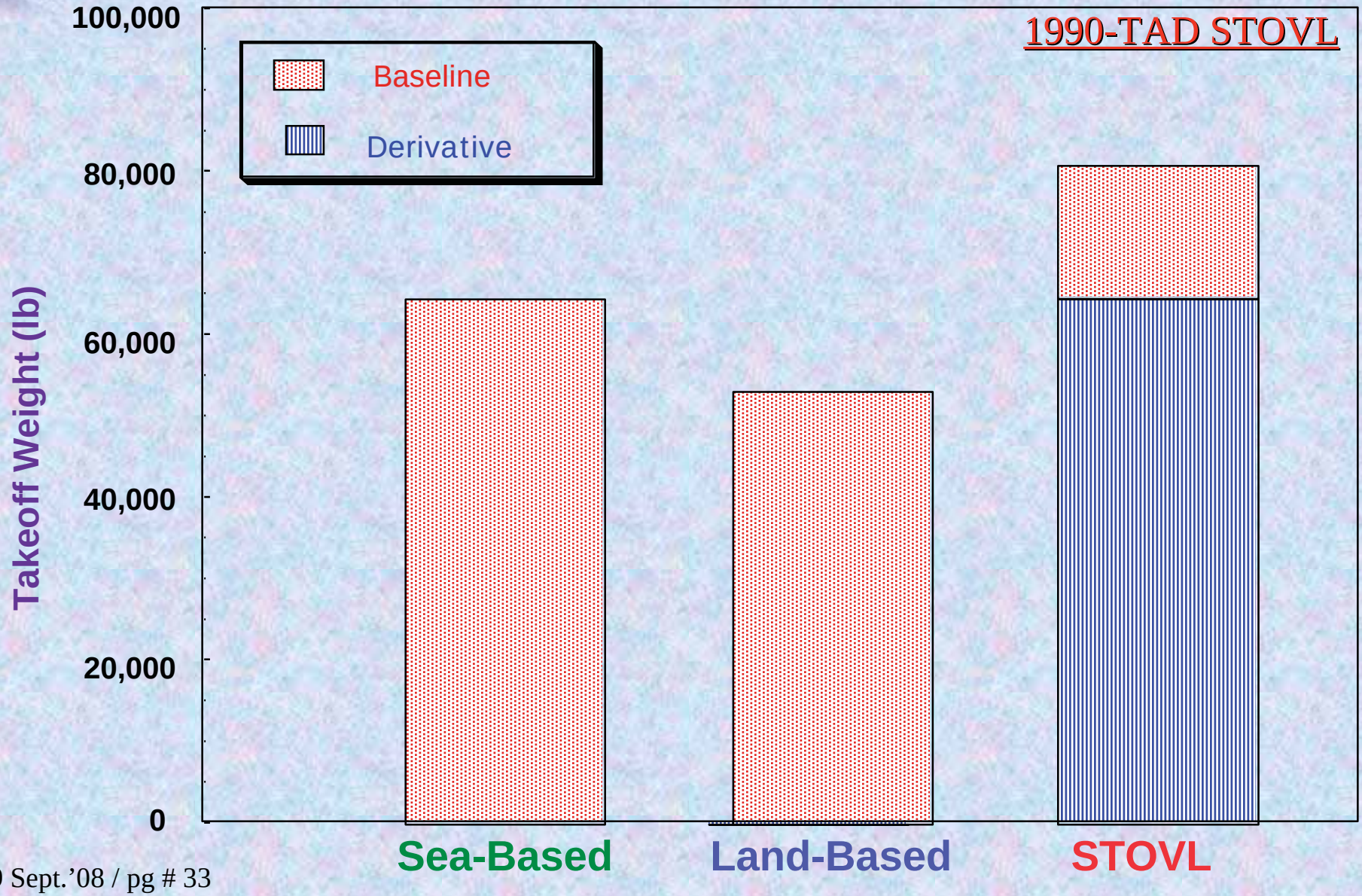


1990-TAD

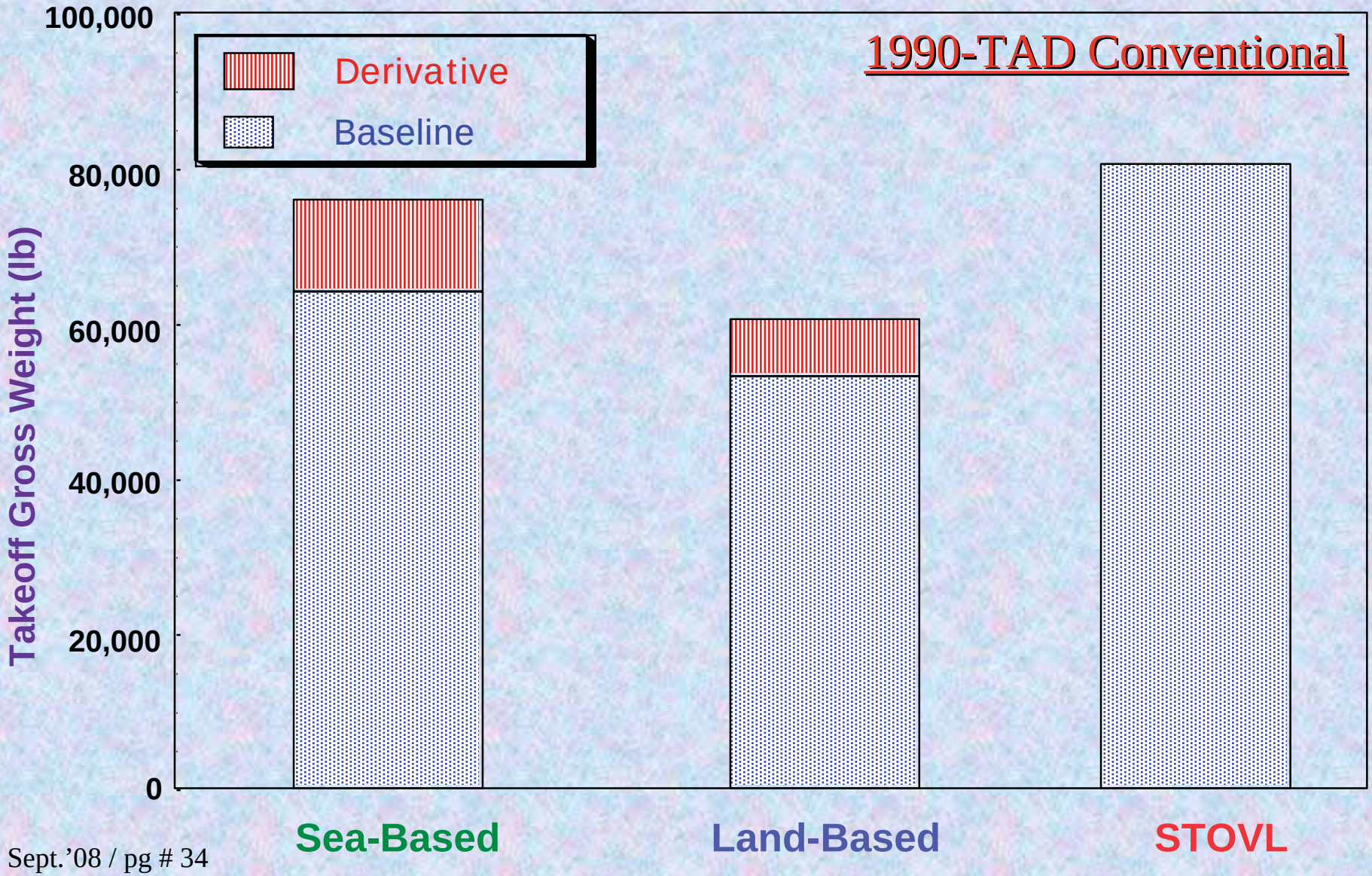
Baseline Aircraft



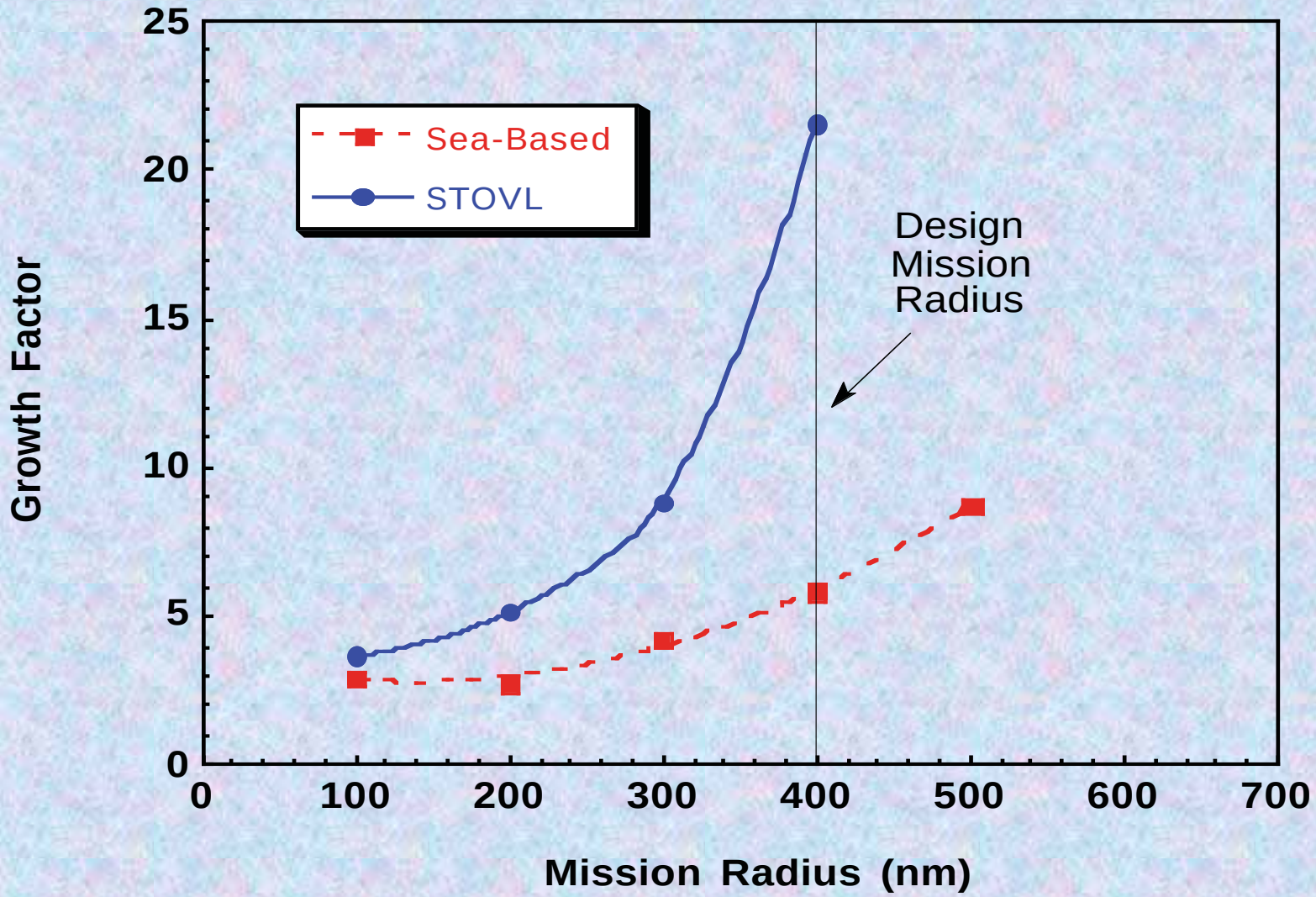
Augmentation in Hover



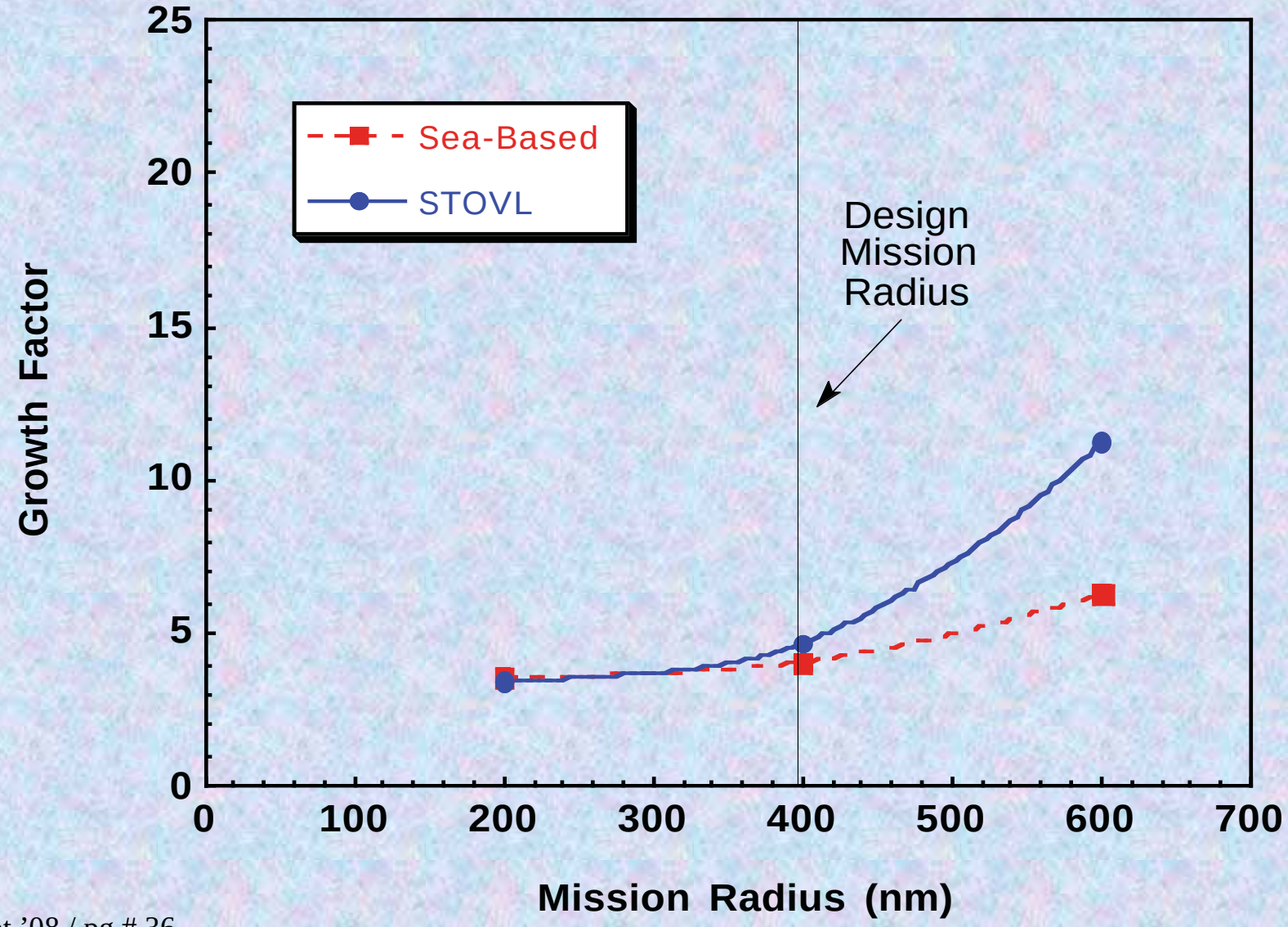
Dry Super-cruise Required



1990-TAD Growth Factor

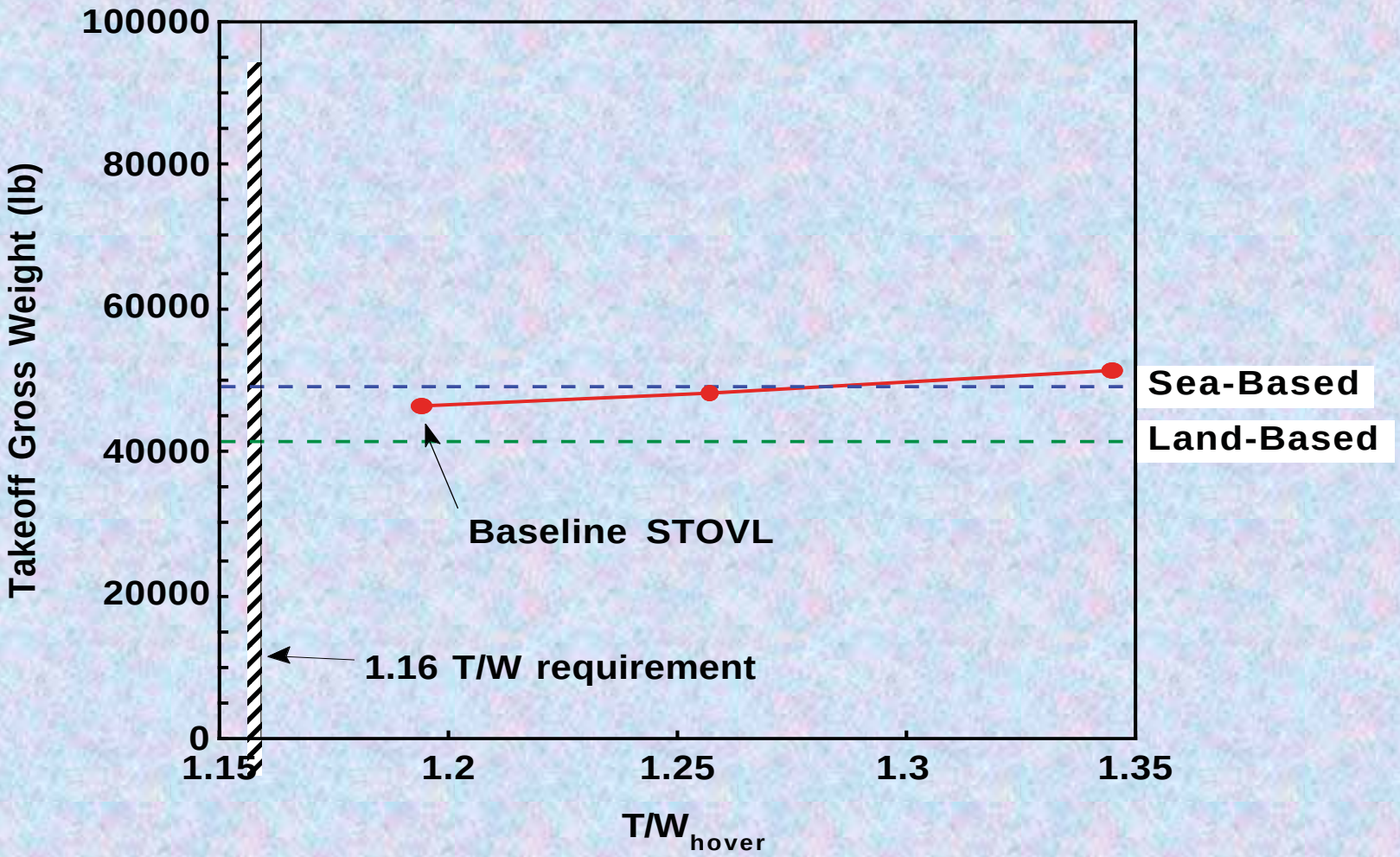


1995-TAD Growth Factor

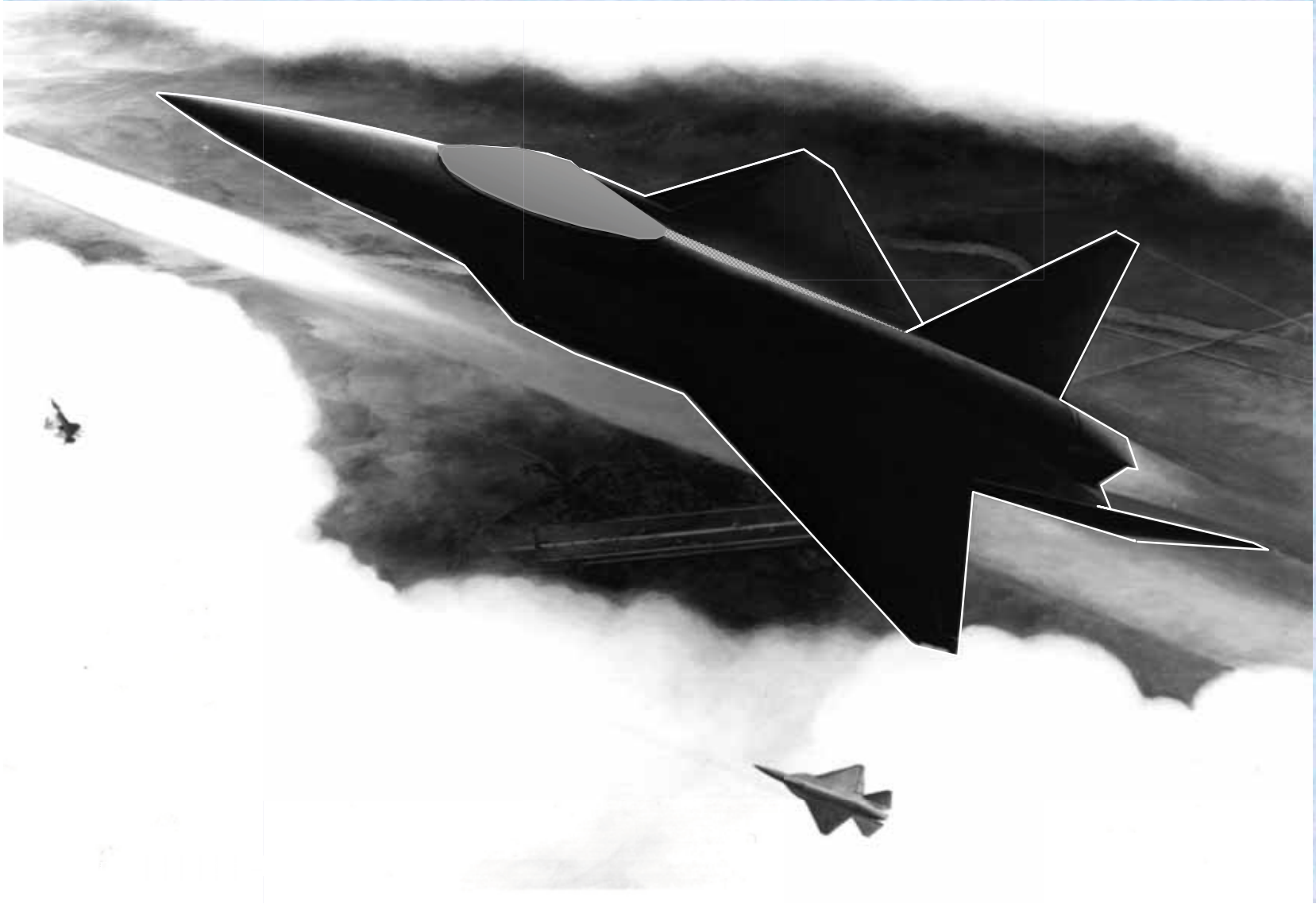


Required Hover Thrust Margin

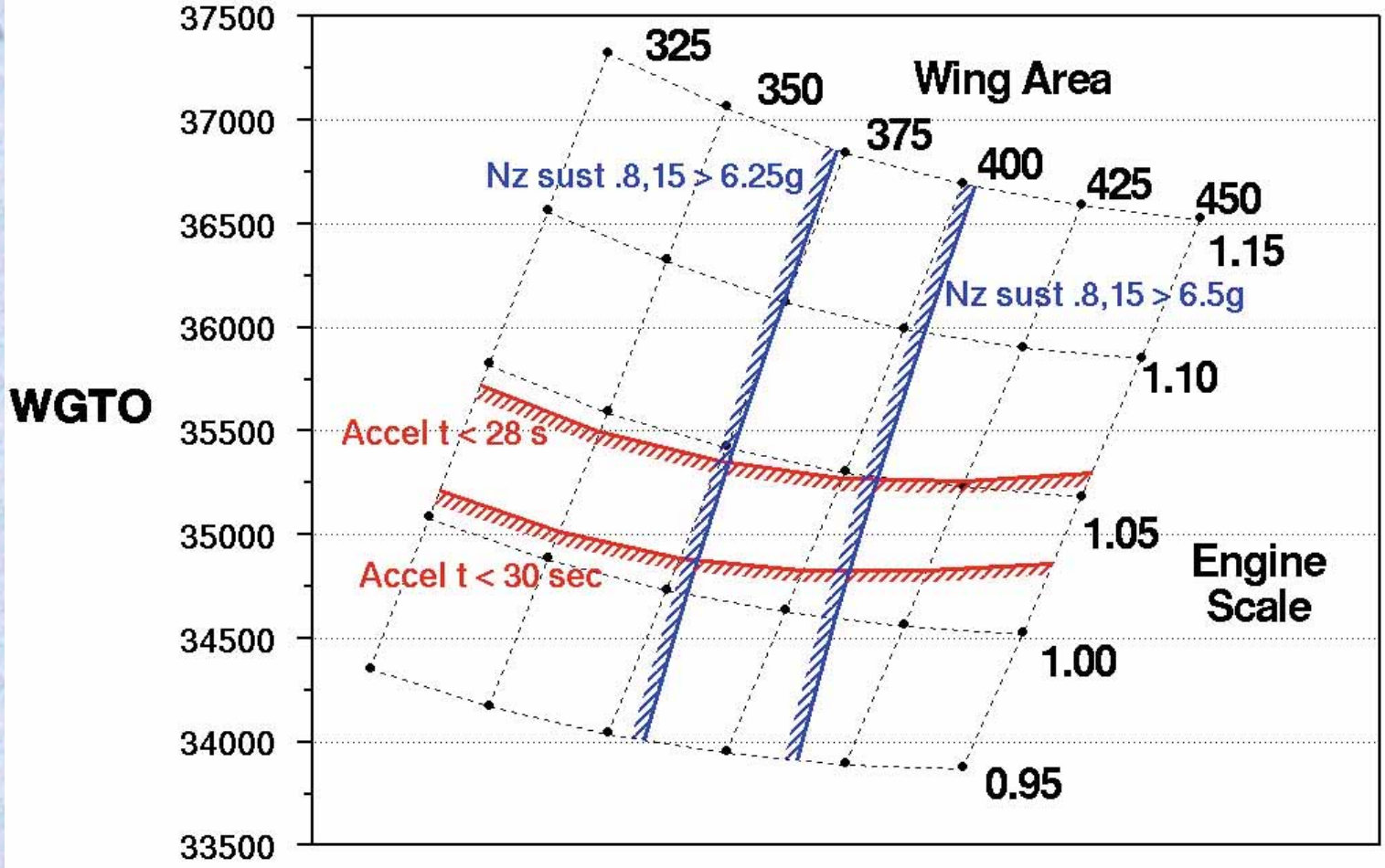
1995-TAD STOVL



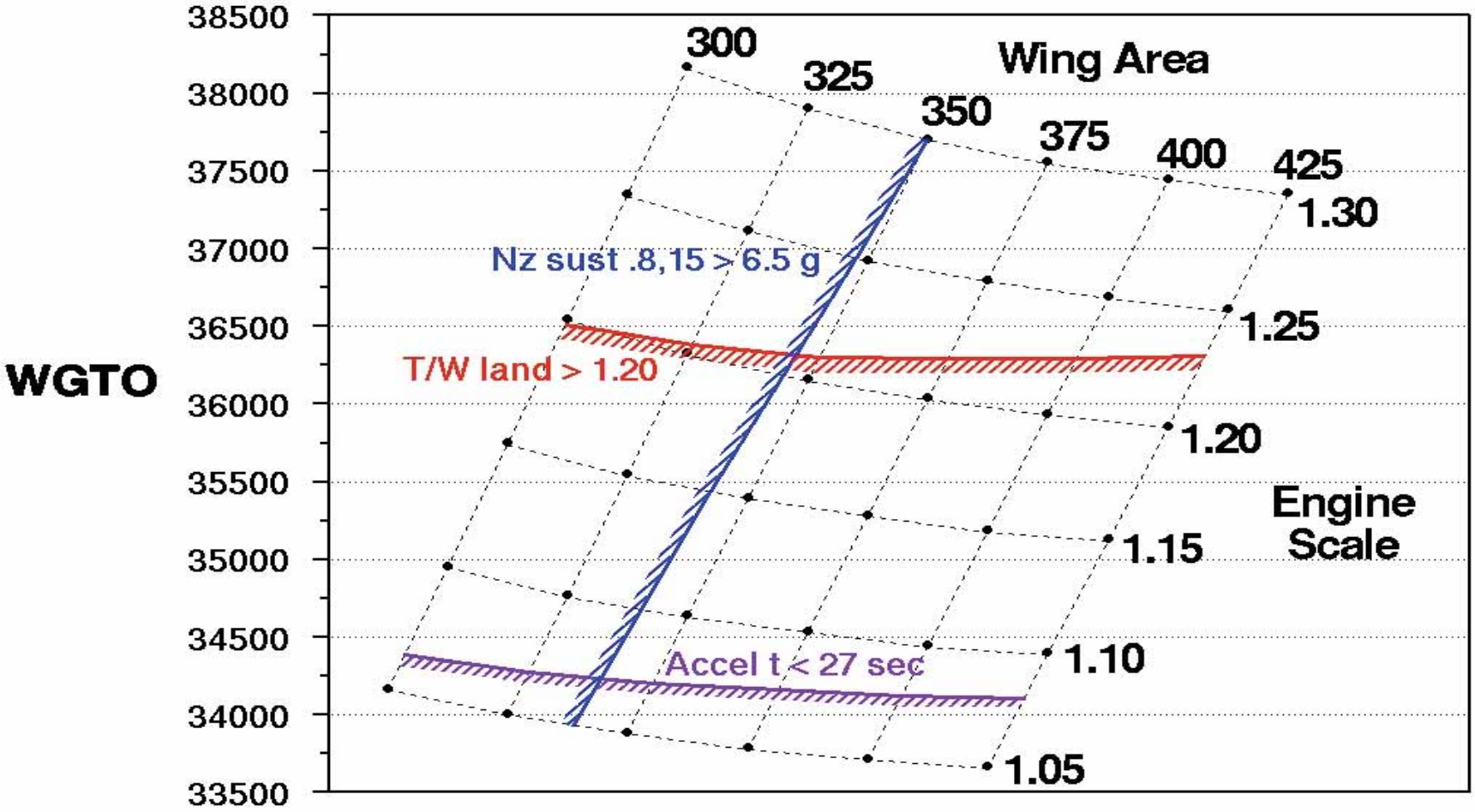
AVID LLC



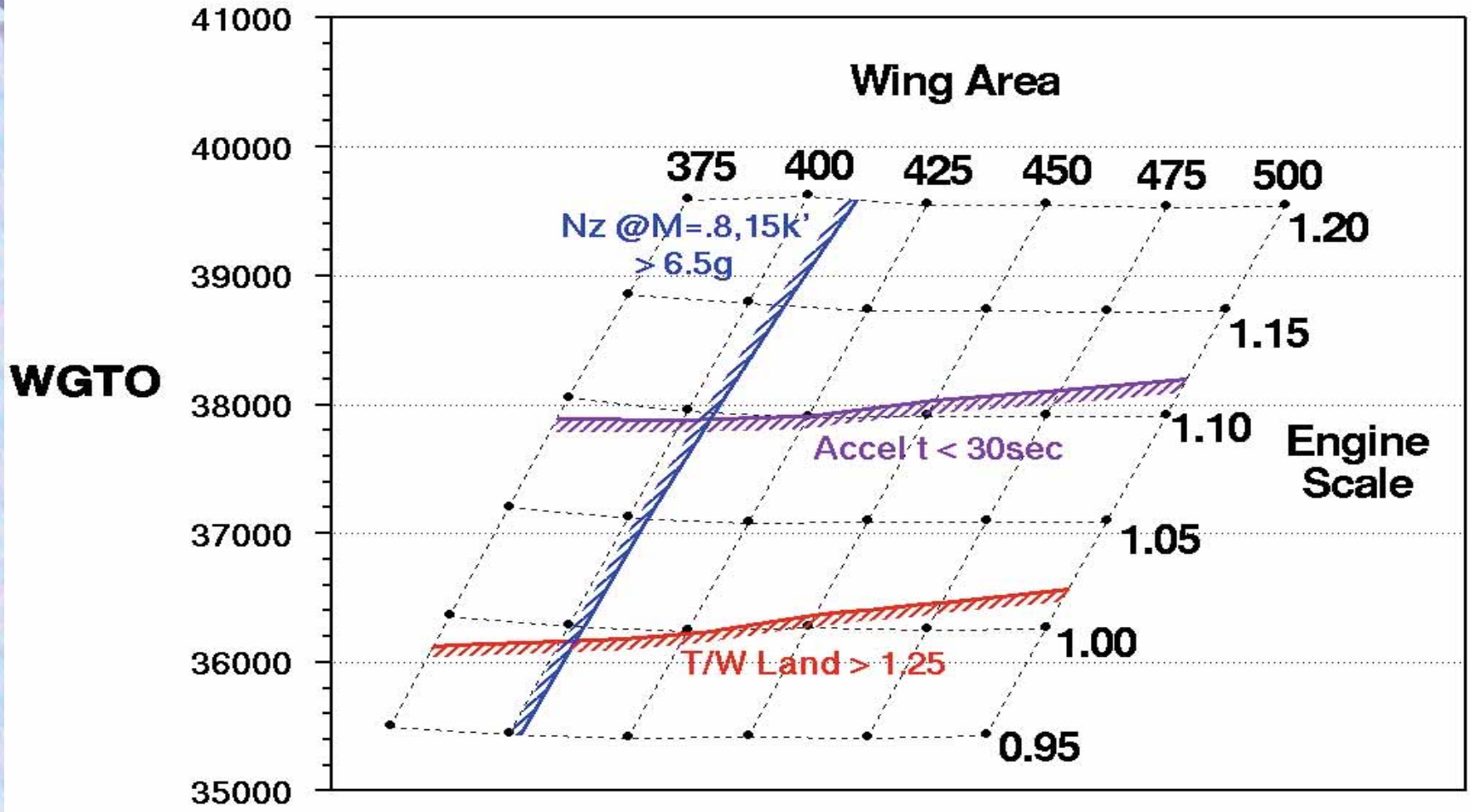
CTOL Sizing Chart



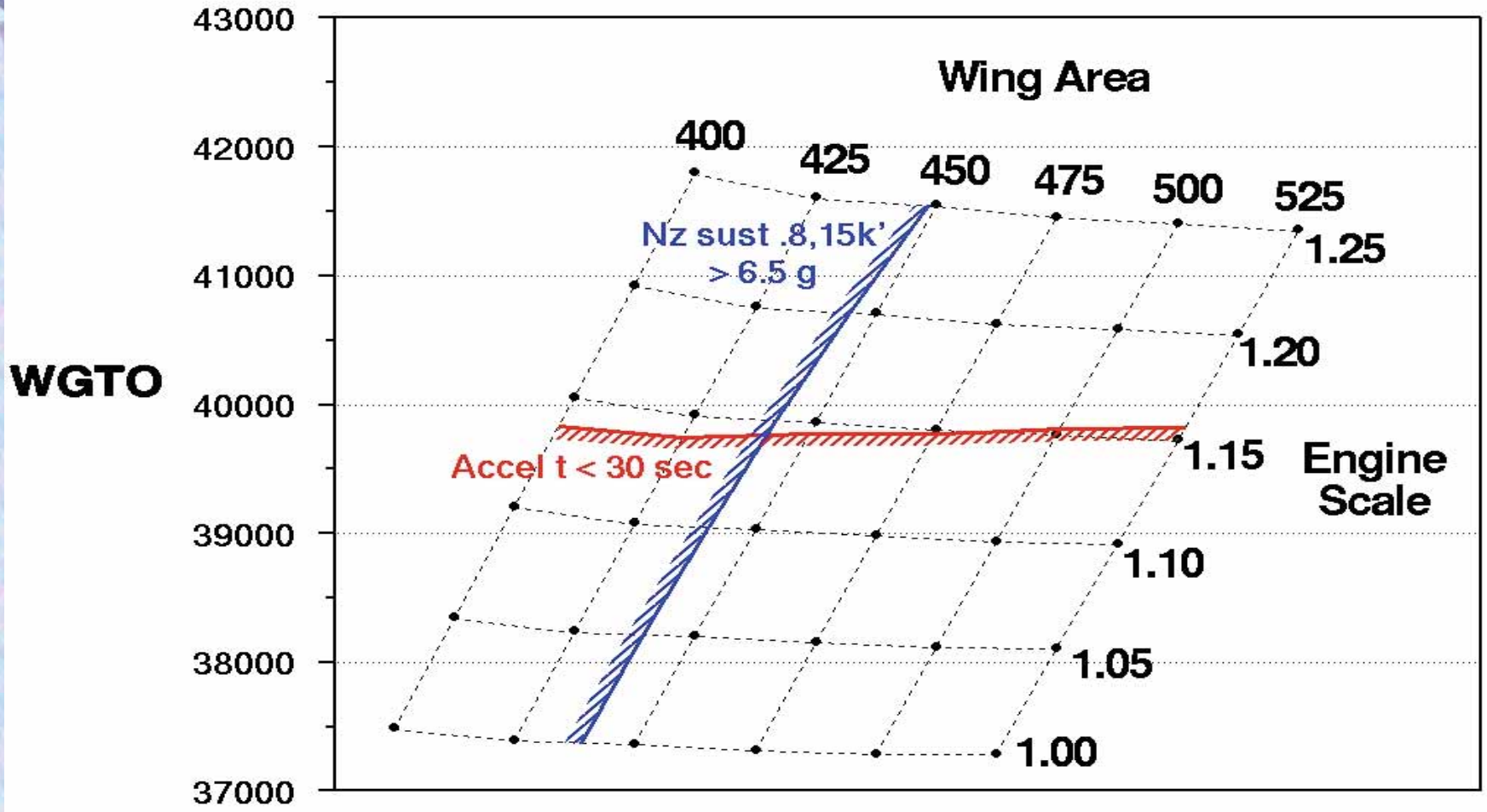
DL Sizing Chart



RFSF Sizing Chart



LPLC Sizing Chart



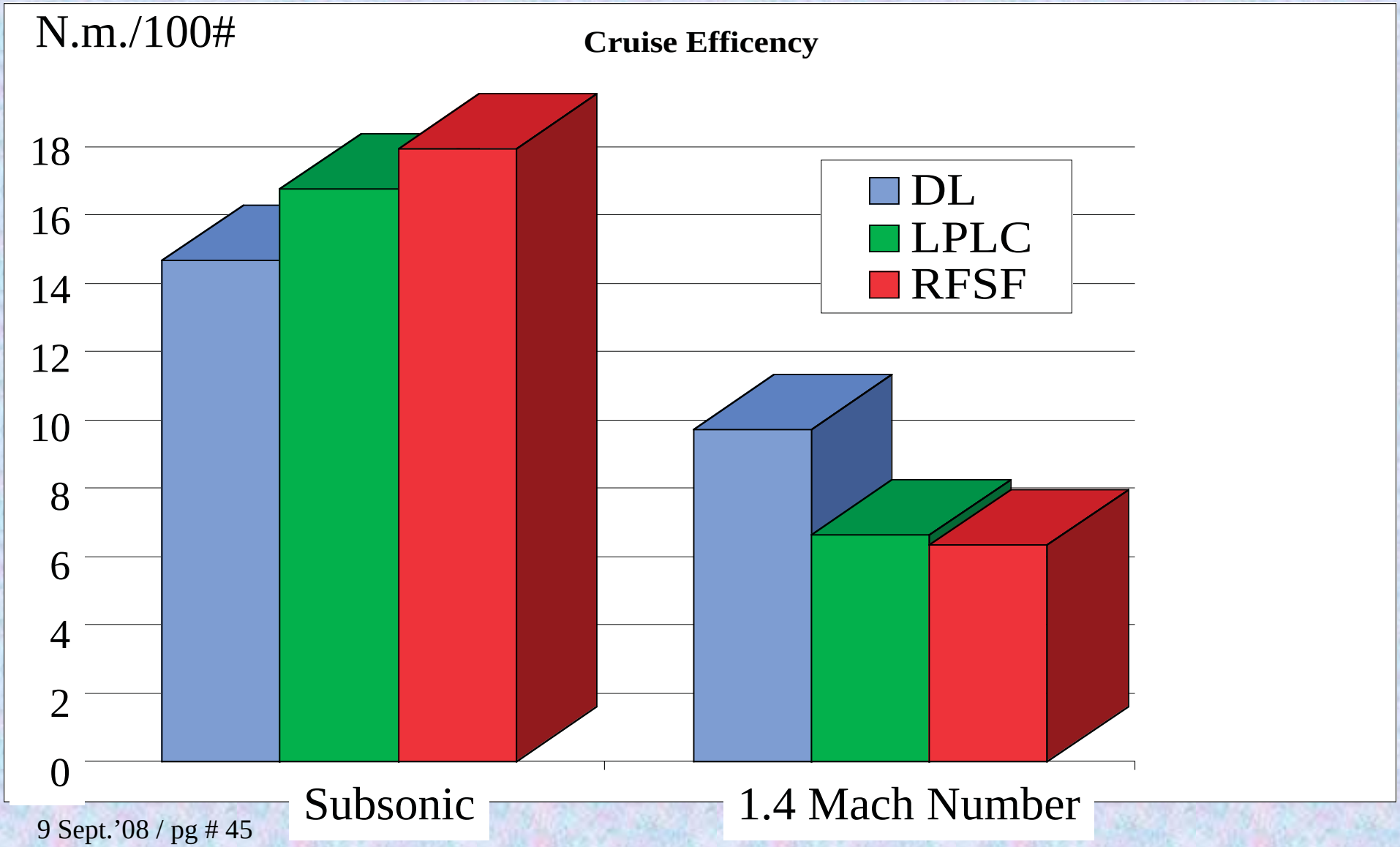
STOVL Baseline Aircraft

		Direct Lift	Remote Fan	L+L/C
T.O. Gross Weight	(LB)	36,331	36,866	39,679
Length	(ft)	48.	54.	54.
Wing Area	(ft^2)	345.	400.	440.
Span	(ft)	29.6	32.8	35.1
Thrust (Vertical landing)		29,289	42,142	47,102
Thrust	(SLS Dry)	29,289	26,021	27,595
Propulsion Weight	(LB)	8,381	8,419	10,014
Engine Weight	(LB)	7,532	6,723	7,097
Fuel Weight	(LB)	11,387	10,698	11,207

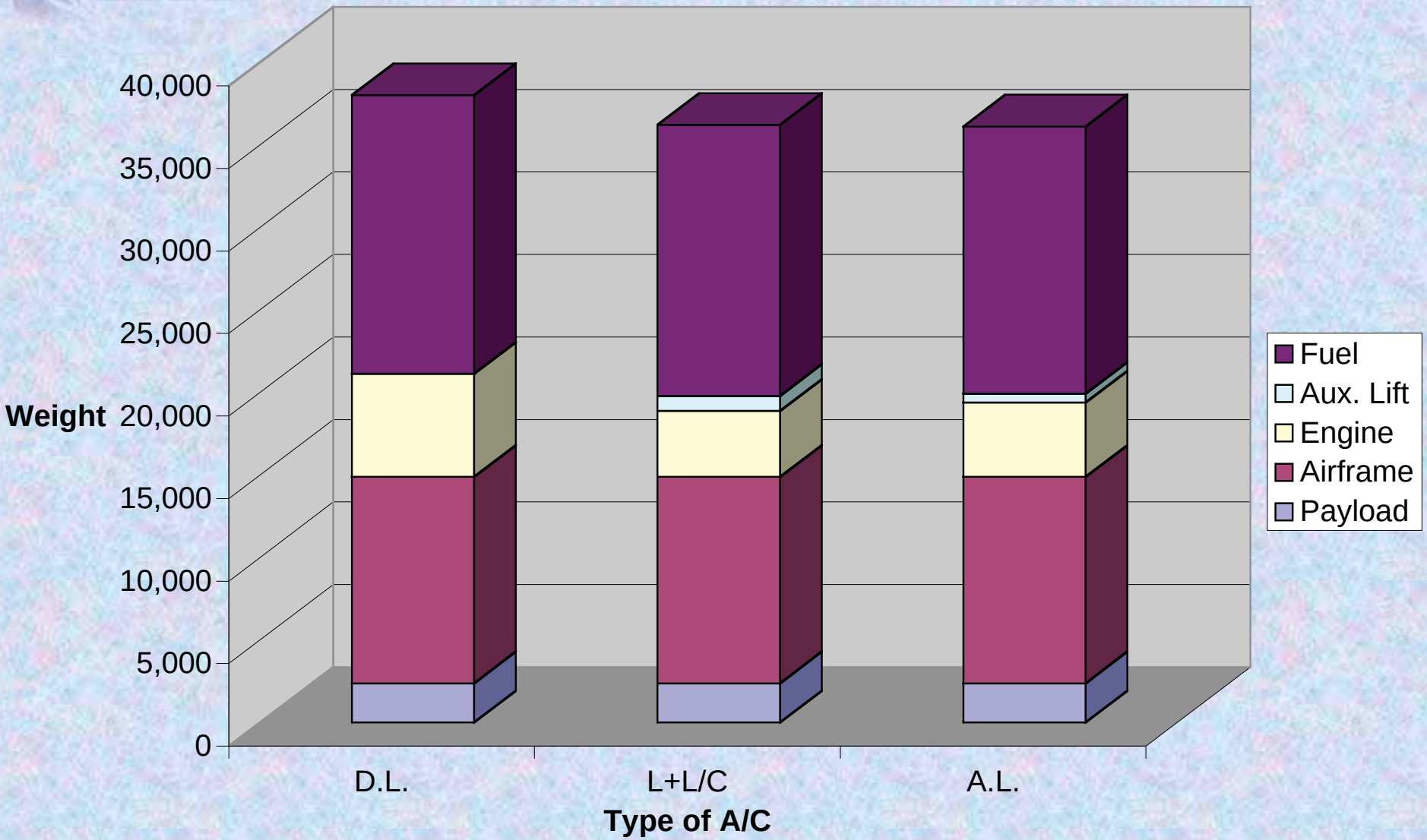
STOVL Aircraft (Ratios)

	Direct Lift	Remote Fan	L+L/C
Growth Factor	3.20	2.37	3.52
Aspect Ratio	2.5	2.6	2.8
Wing Loading (LB/ft^2)	105.3	92.2	90.2
Vertical Thrust/W_{PS}	3.49	5.01	4.70
Dry Thrust/TOGW	0.81	0.71	0.70
Max Thrust/TOGW	1.30	1.14	1.12
ESF	1.21	1.08	1.14
Prop. Sys. Fraction	23.1%	22.8%	25.2%
Fuel Fraction	31%	29%	28%

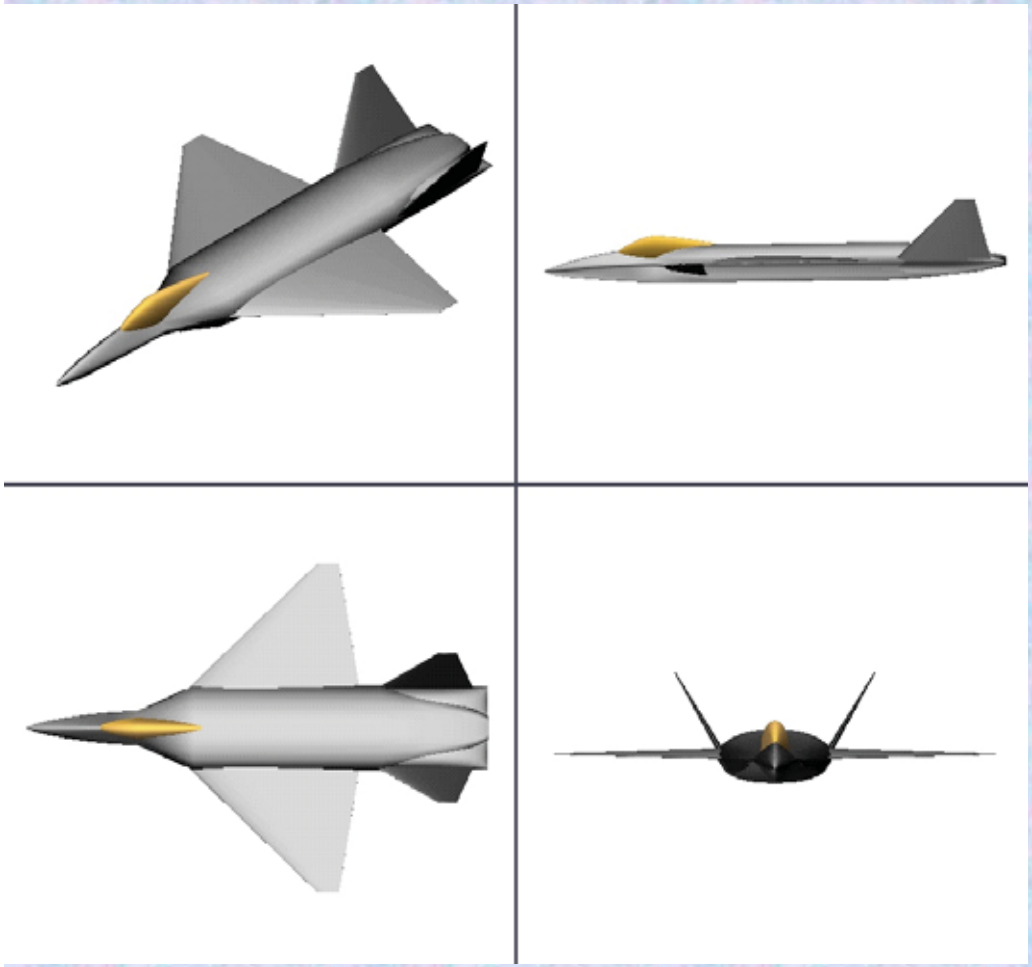
Cruise Efficiency



Weight Breakdown

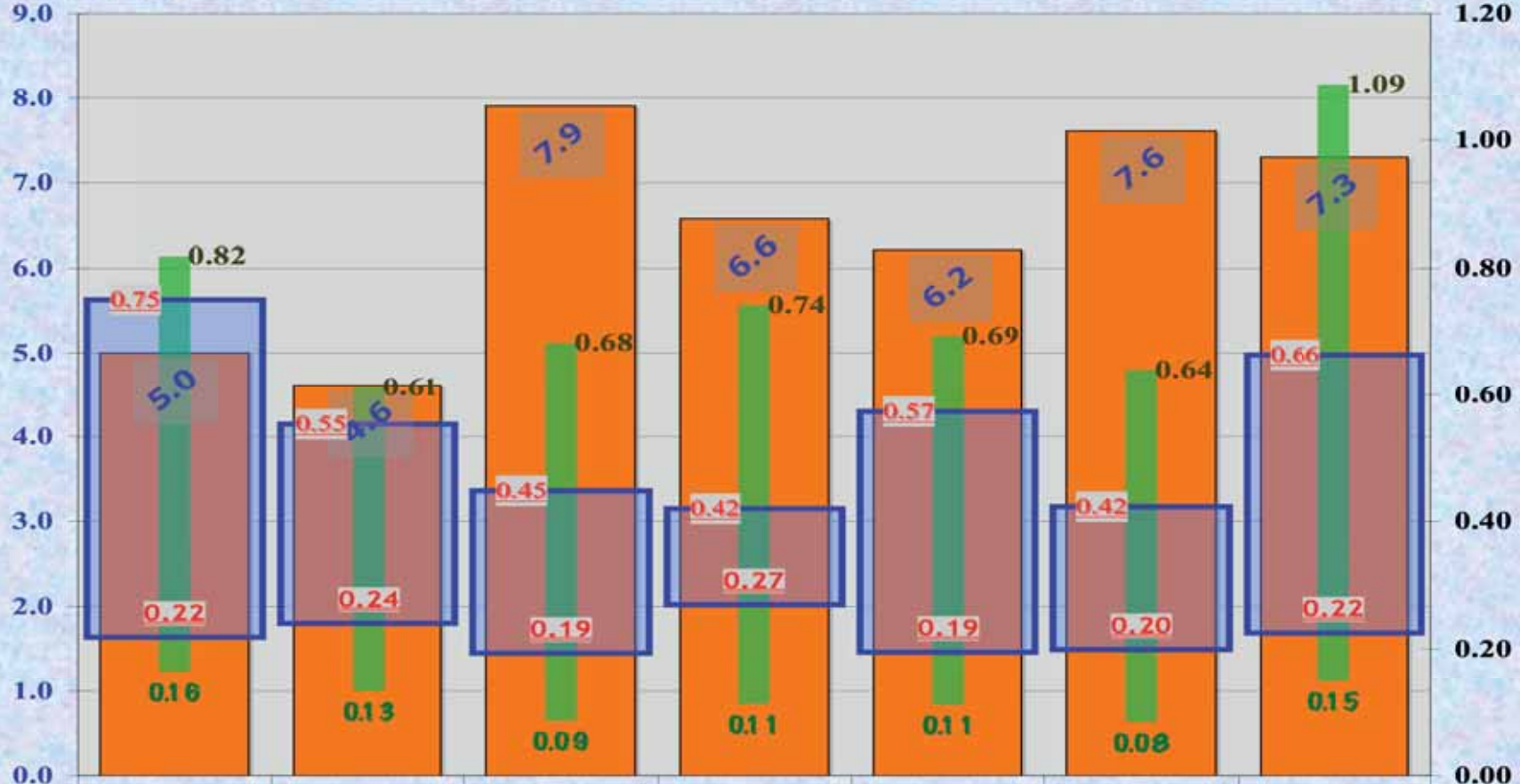


Conclusions



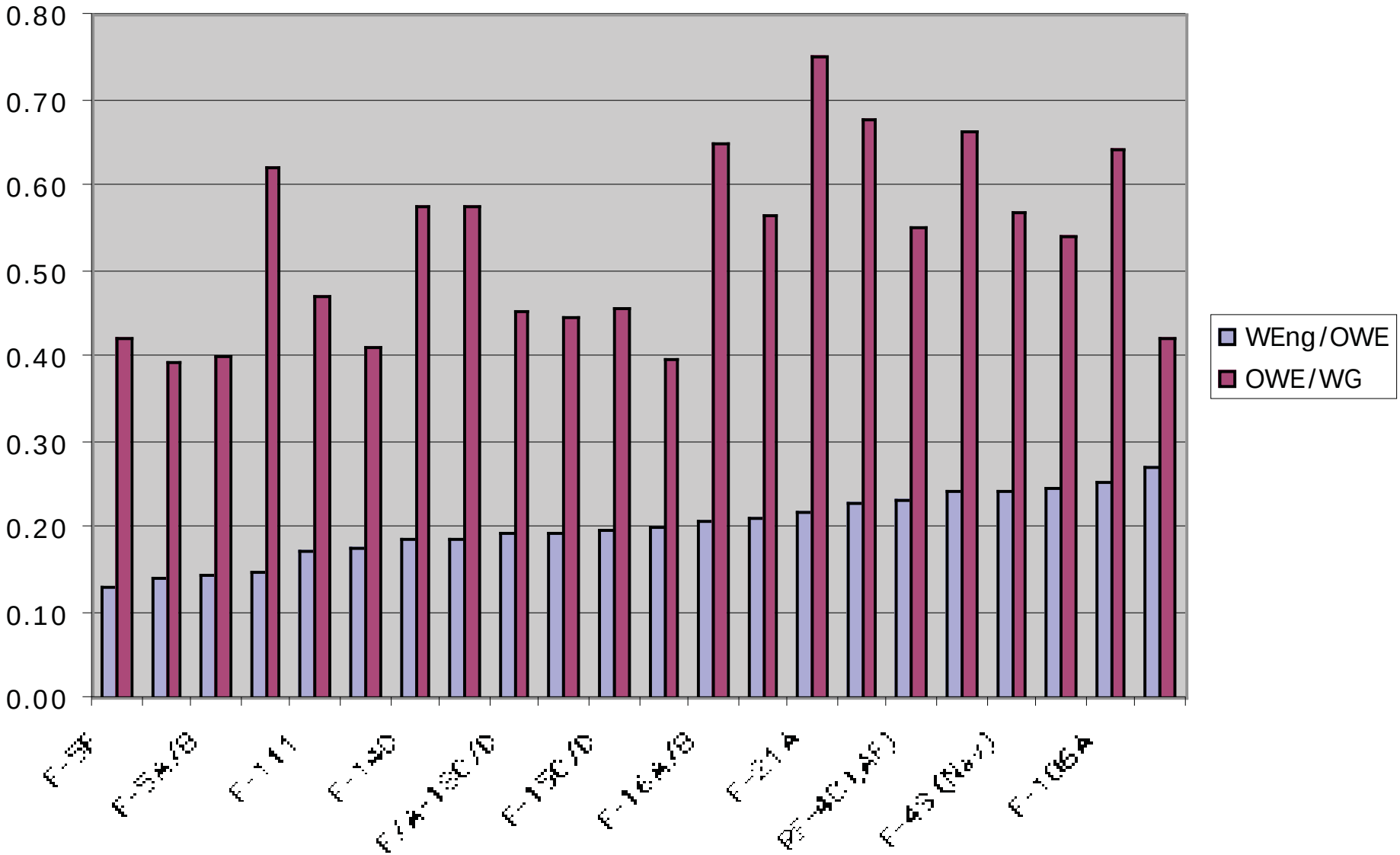
- Improved engine technology allows the elimination of landing thrust-to-weight as the main STOVL design constraint.
- The STOVL propulsion system decision drives the aerodynamic shape.

Engine Weight vs. Empty Weight



	F-21	F-4	F/A-18	AV-8	F-14	F-15	F-16
T/Weng	5.0	4.6	7.9	6.6	6.2	7.6	7.3
OWE/Wg	0.75	0.55	0.45	0.42	0.57	0.42	0.66
T/Wg	0.82	0.61	0.68	0.74	0.69	0.64	1.09
WEng/Wg	0.16	0.13	0.09	0.11	0.11	0.08	0.15
Weng/OWE	0.22	0.24	0.19	0.27	0.19	0.20	0.22

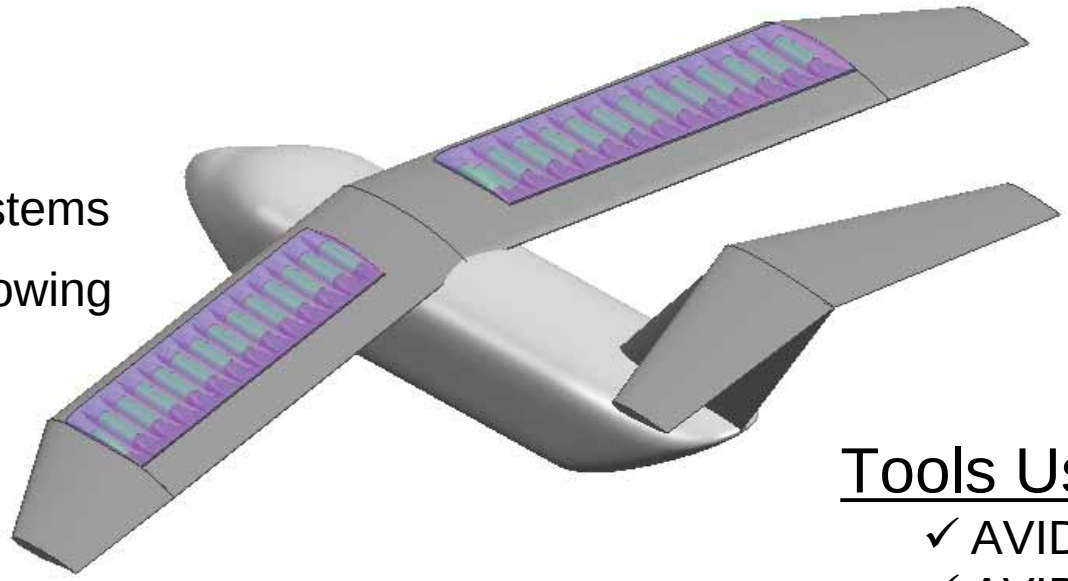
Engine Weight vs. Empty Weight



Distributed Propulsion

DARPA PM: Dr. Thomas Beutner (TTO)

Advanced ESTOL transport configuration development incorporating distributed propulsion technology and airframe / propulsion integration.

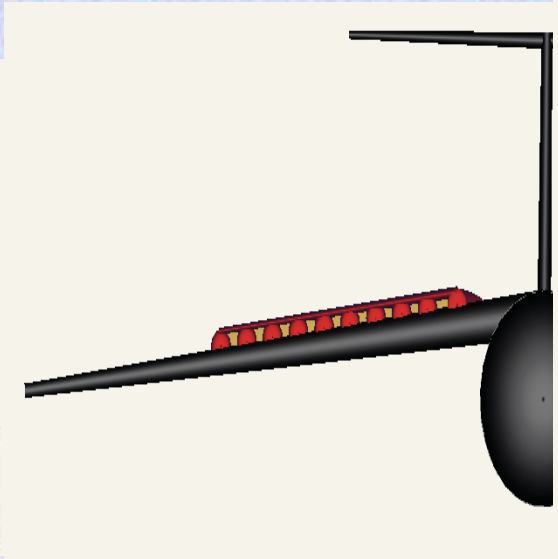


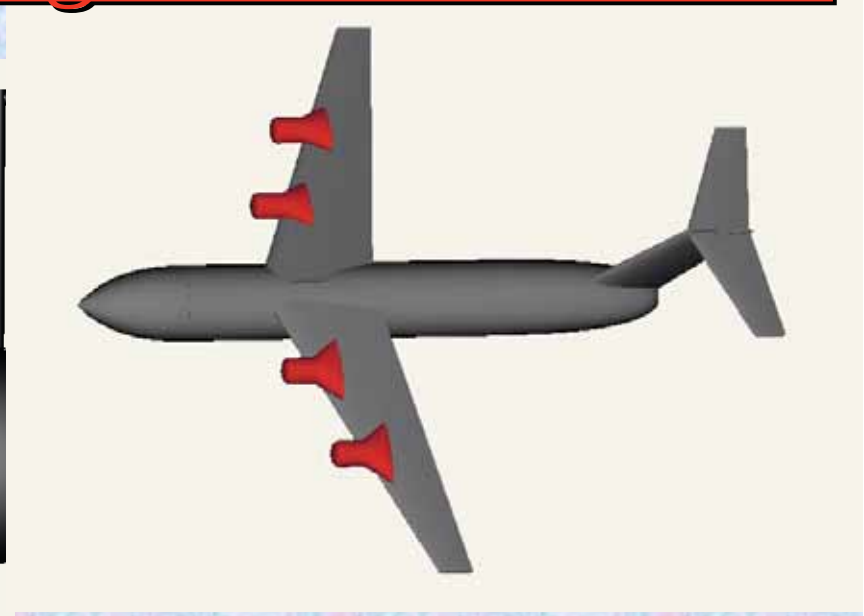
- ✓ Powered high-lift systems
  - Upper surface blowing
  - Augmenter wing
  - Blown tails
- ✓ 278-ft field length
- ✓ 15,000 lb -- 25,000 lb payload
- ✓ Demonstrated distributed propulsion performance
- ✓ Identified new benefits for Distributed Propulsion

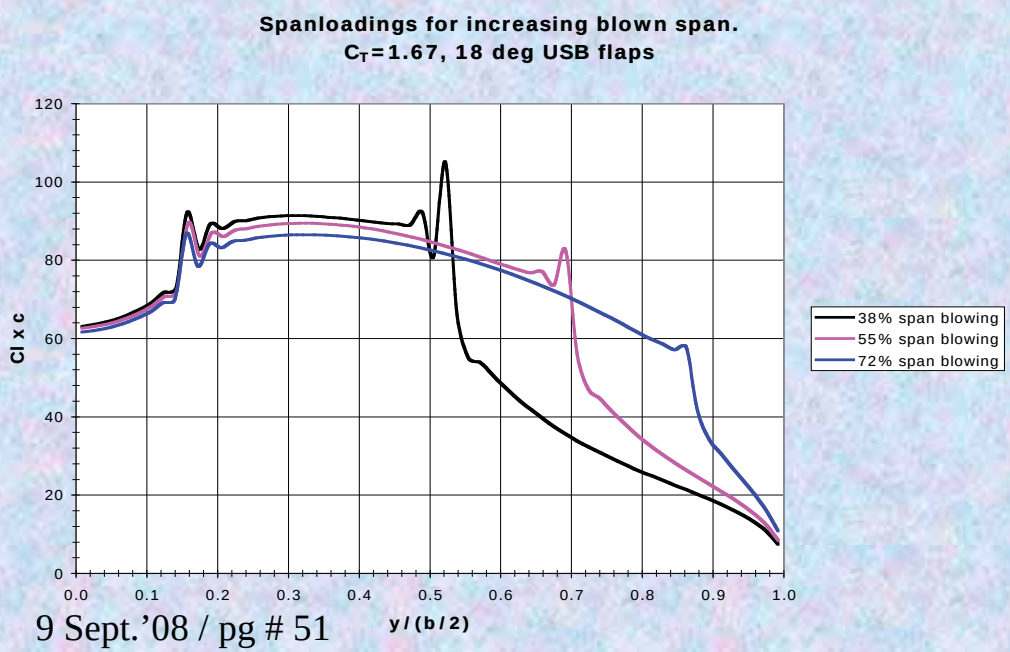
Tools Used

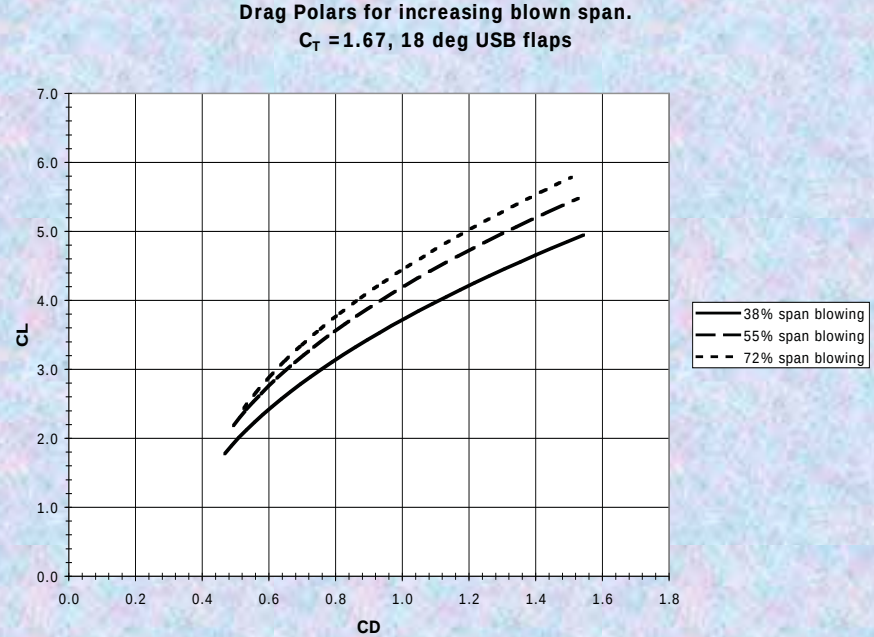
- ✓ AVID RAPT
- ✓ AVID HighLift
- ✓ AVID ACS
- ✓ FUN3D
- ✓ CFL3D
- ✓ USM3D

Span Blowing versus Total Lift

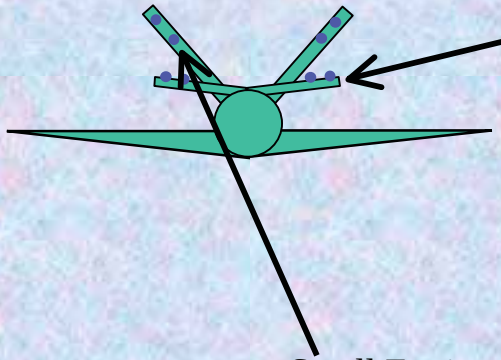




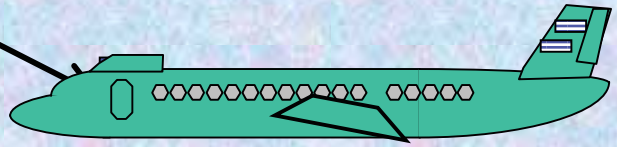




Notional Demonstrator



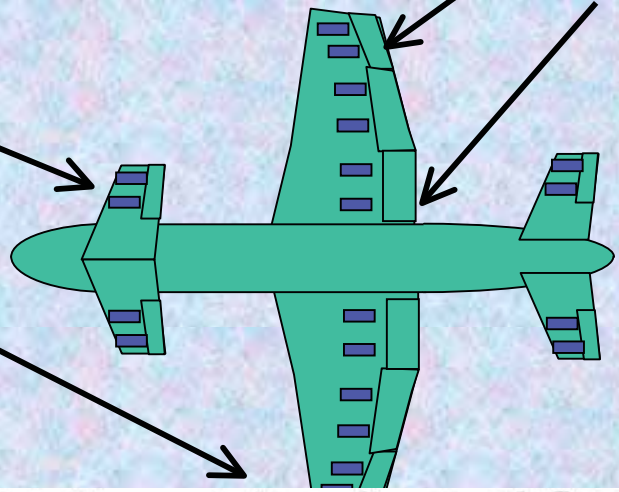
Canard over door



Variable # of engines used in cruise (designed to cruise at best SFC)

Small Engines "blowing" Flaps During STOL operations

Small Engines "blowing" Control Surfaces during STOL operations to reduce size



Integrated Flight-Propulsion Control Concepts for Supersonic Transport Airplanes

Frank W. Burcham, Jr. and Glenn B. Gilyard
NASA Ames-Dryden, Edwards, CA

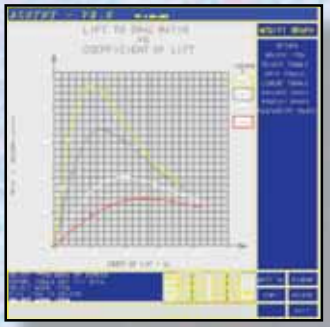
Paul A. Gelhausen
NASA Ames Research Center, Moffett Field, CA

AVID-ACS Type Output

- Engine is sized by maneuver or VL (1.2*GW)
- Fuel is generated by Fuel burn:
  - ✓ Thrust required = weight/ (L/D)
  - ✓ Fuel = Thrust * SFC
- Airframe weight is structure to hold everything:
  - ✓ Fuel tanks = Fuel weight * 3%
  - ✓ Landing Gear = TOGW * 6%
  - ✓ Tails = Control power sizing
  - ✓ Wing = f (AR, Sweep, Area, Taper, T/C)

ACSYNT Institute: Aircraft Design Tools

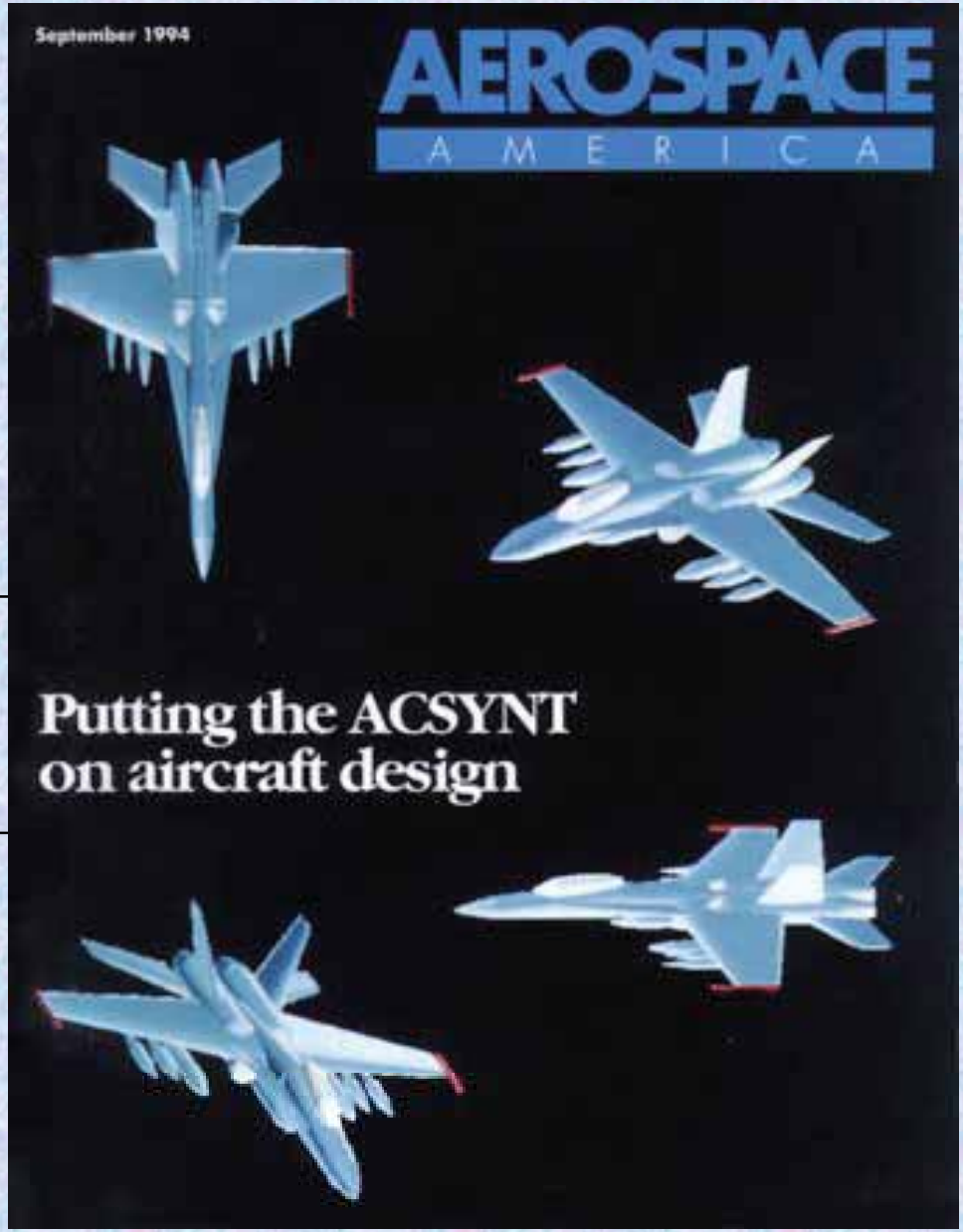
Parametric design tool for aircraft synthesis...



Concept Development	*Preliminary Design*
ACSYNT	

- *Lots of Designs*
- *Tradeoff Studies*
- *"Requirements Optimization"*

- *In-depth analysis*
- *Narrowed to few designs*
- *Detailed optimization*



ACSYNT Drawbacks

- Practical – Human designer not informed as to why final design was chosen
- Technical – Can't handle step changes (i.e. number of engines, type of control surface). Must use continuous functions in coding.

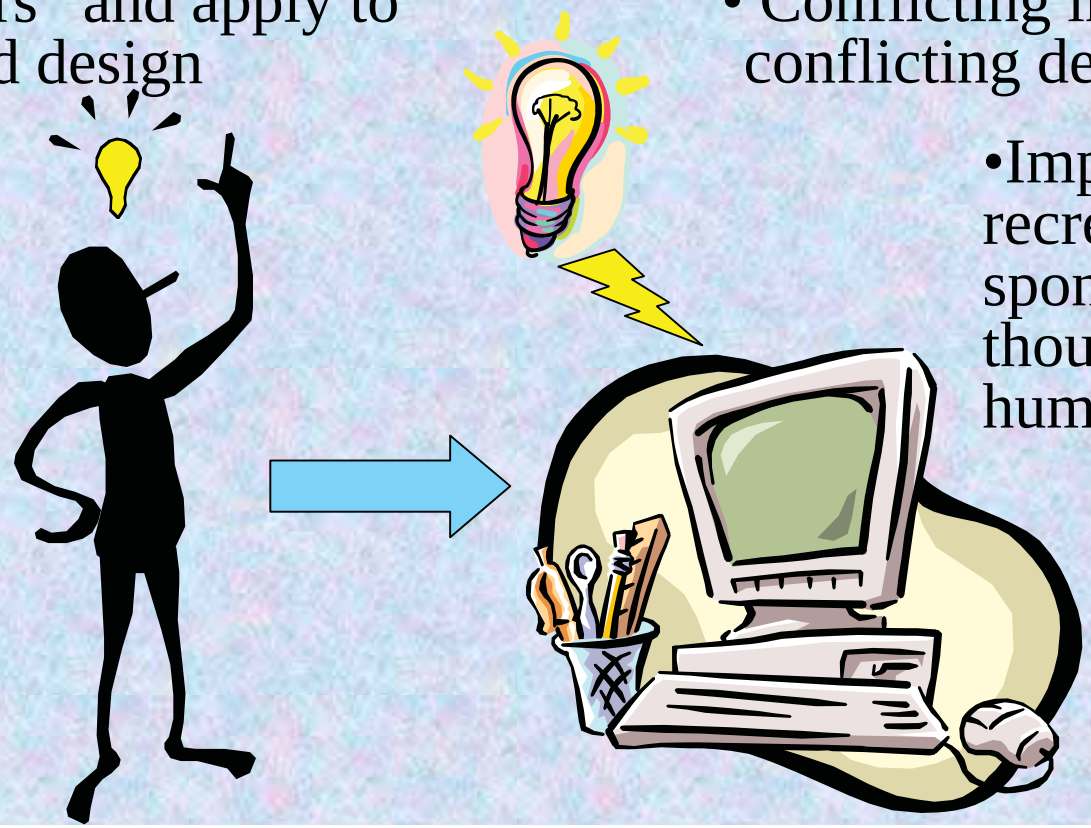
Artificial Intelligence for Aircraft Design

PROS

- Hailed as "Future of Aircraft Design"
- Capture the thoughts of the "great designers" and apply to computer aided design programs

CONS

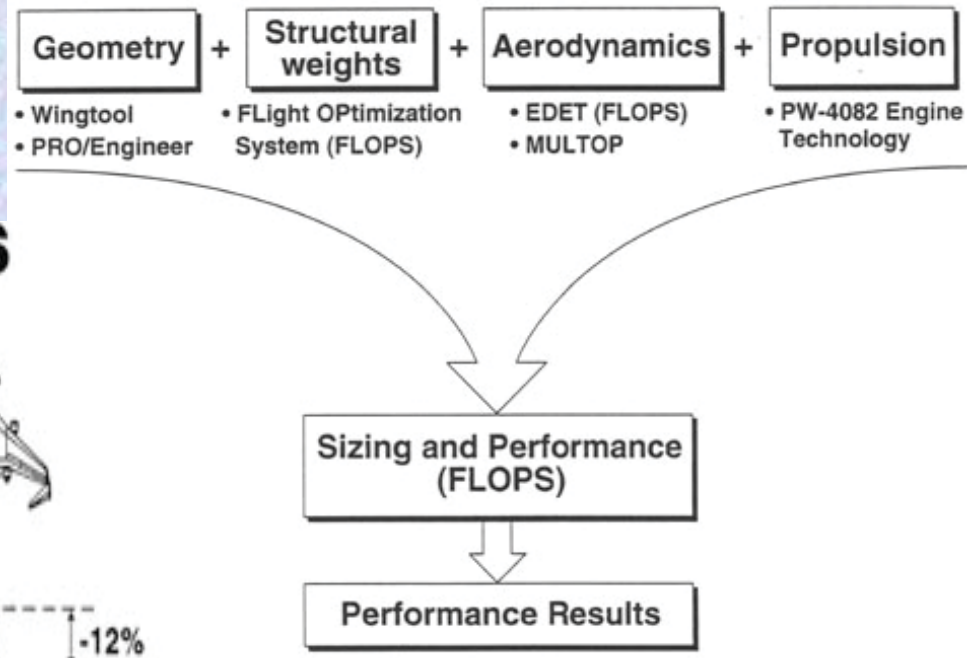
- Designers are constantly evolving, requires evolving code
- Conflicting inputs from conflicting designers
- Impossible to recreate spontaneous thoughts of humans



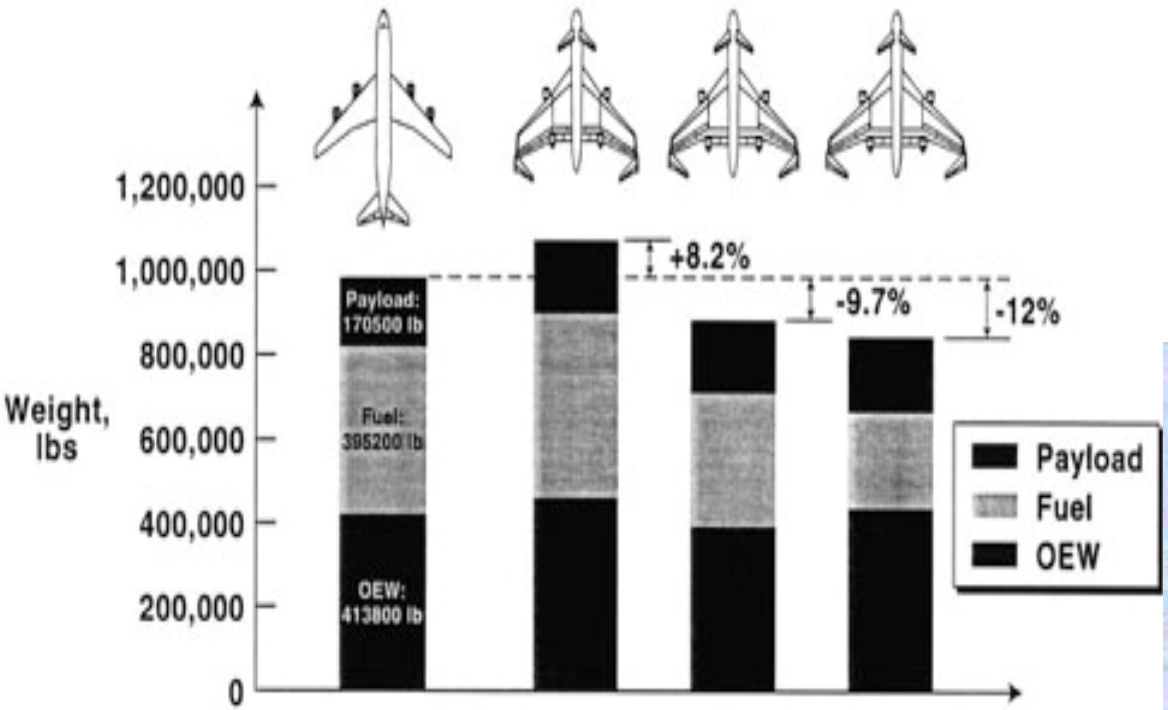
Goals of Computer Aided Aircraft Design Optimization Programs

- Reduce dependence on wind tunnel testing
- Computer code offers “Real Time Design”
- Much smoother transition from paper to prototype
- Reduces common “headaches” associated with current aircraft design
- No more “Point Design”

DESIGN AND ANALYSIS METHOD



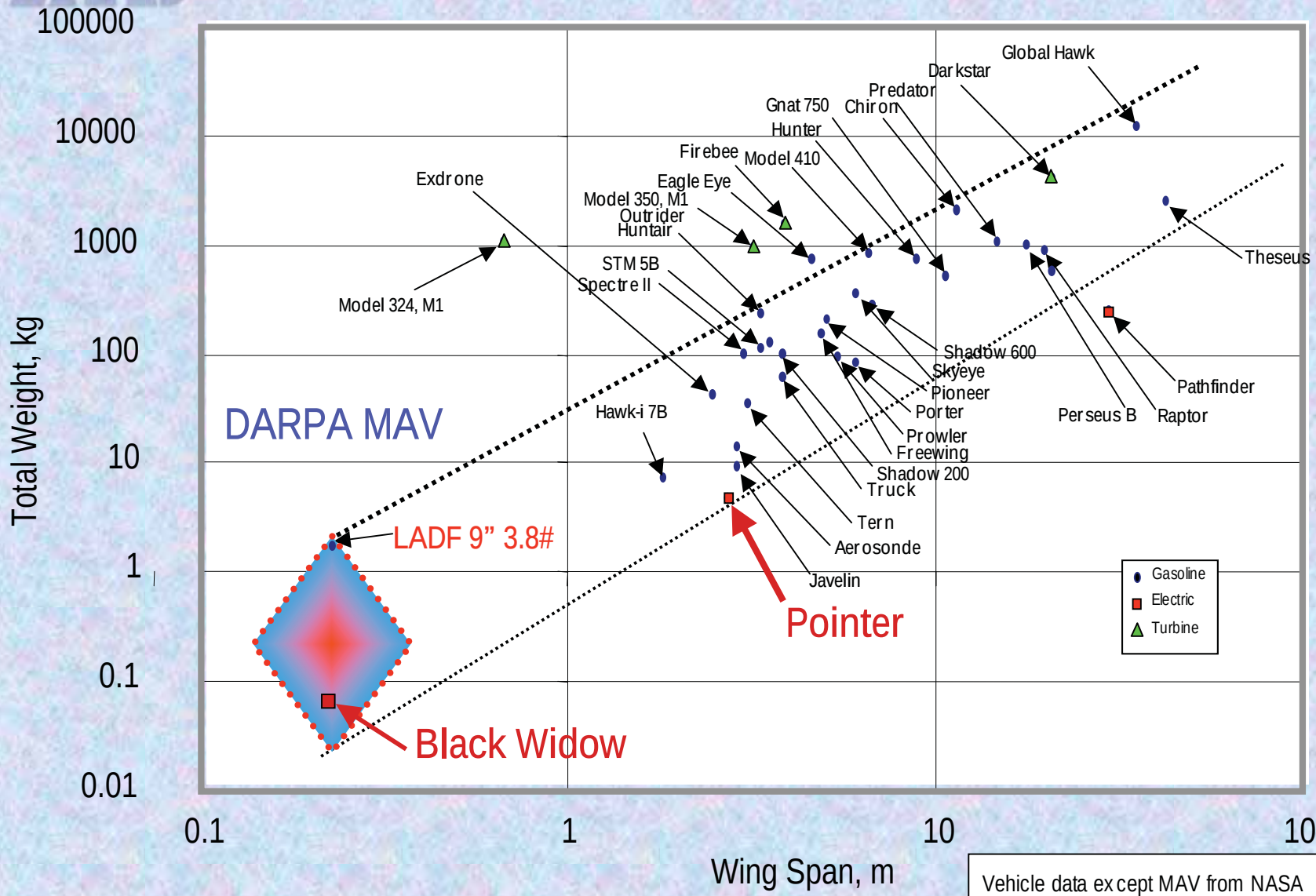
OPTIMIZATION RESULTS



Model	Conventional Baseline	C-Wing 1	C-Wing 2	C-Wing 3
Material	Composite	Composite	Composite	Composite
AR	8.42	4.07	6	6
Wing area, ft	8136	15116	11052	12514
Thrust/Engine, lb	52509	74399	46691	45251
Span, ft	229	236	245	260
Goldschmied factor	-	1.0	1.0	2.0
TOGW	979500	1060200	884900	861500

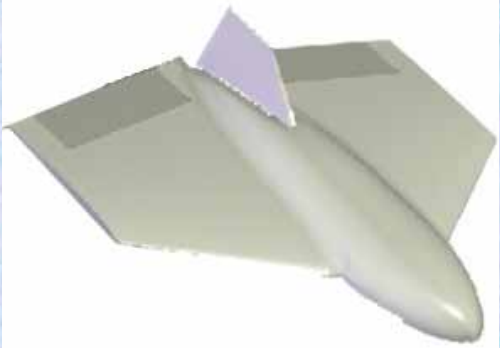
http://aero.stanford.edu/reports/nonplanarwings/CWingOpt.html

Unmanned Air Vehicles



Vehicle data except MAV from NASA GSFC / Wallops UAV Database http://uav.wff.nasa.gov/db/uav_index.html

Micro Air Vehicles



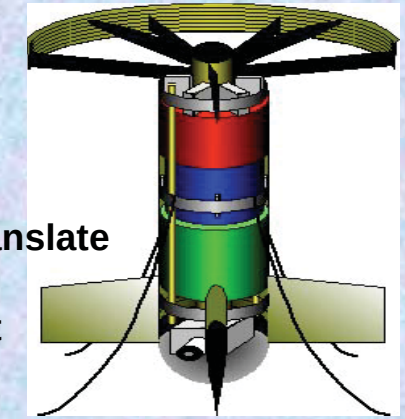
Lockheed Sanders

MicroSTAR

100 g.
5 km range, 30 min.
Autonomous Nav.
Video imagery

Kolibri

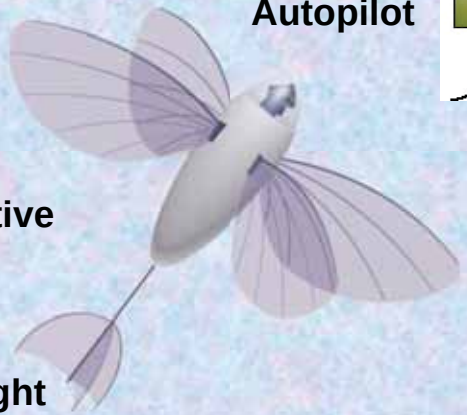
320 g.
30 min.
Hover/translate
GPS
Autopilot



Lutronix

Mentor

50 g.
electrostrictive
polymer
artificial
muscle
Flapping flight



Stanford Research Institute

Caltech

Microbat

10 g.
3 min.
Acoustic sensors
MEMS wings

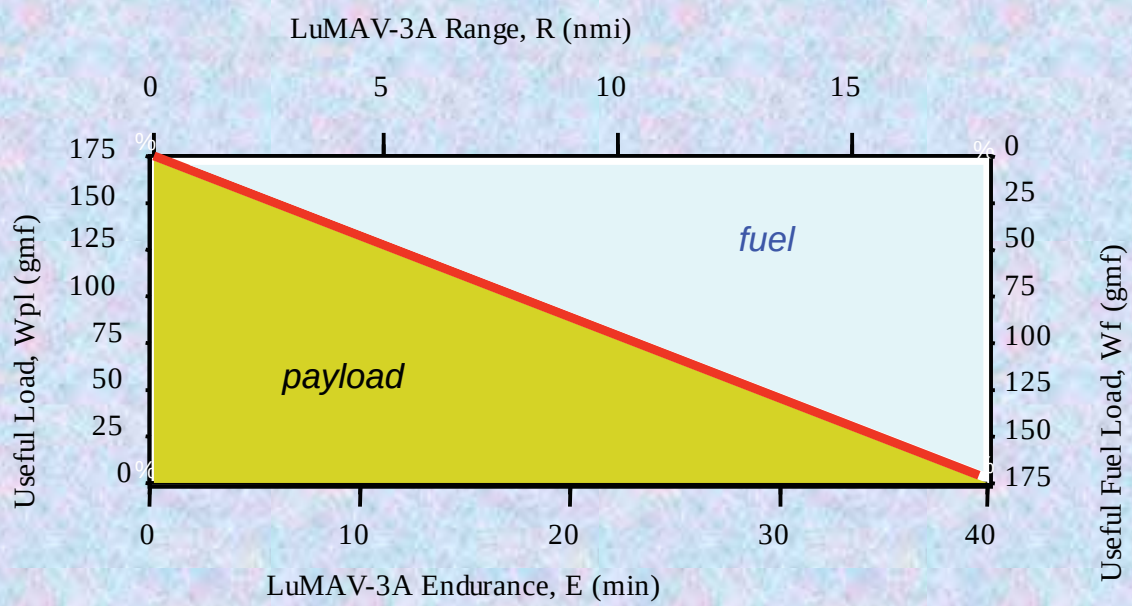
Black Widow

50 g.
1 km range
Teleoperated
Video imagery

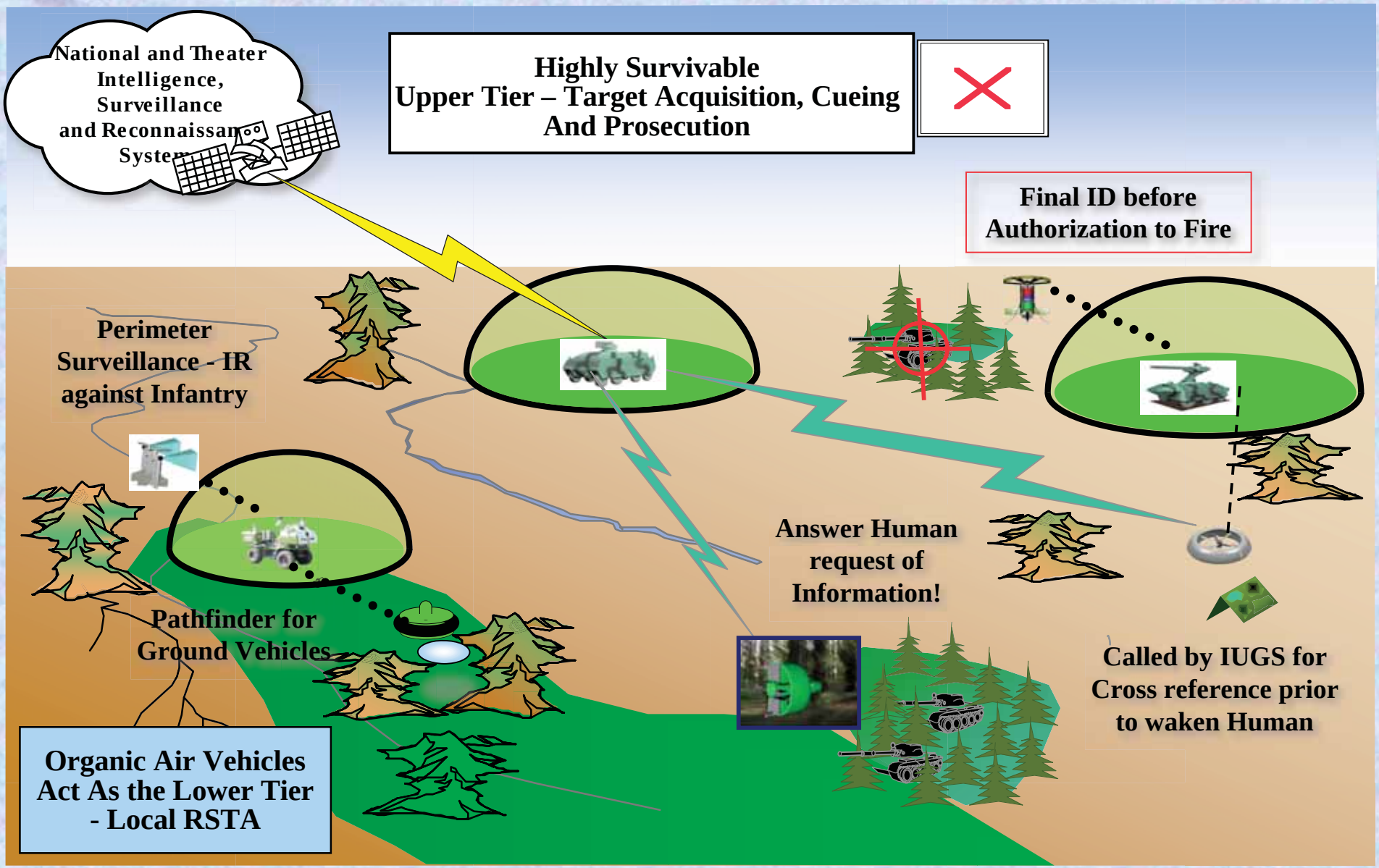
AeroVironment

Kolibri Micro Air Vehicle

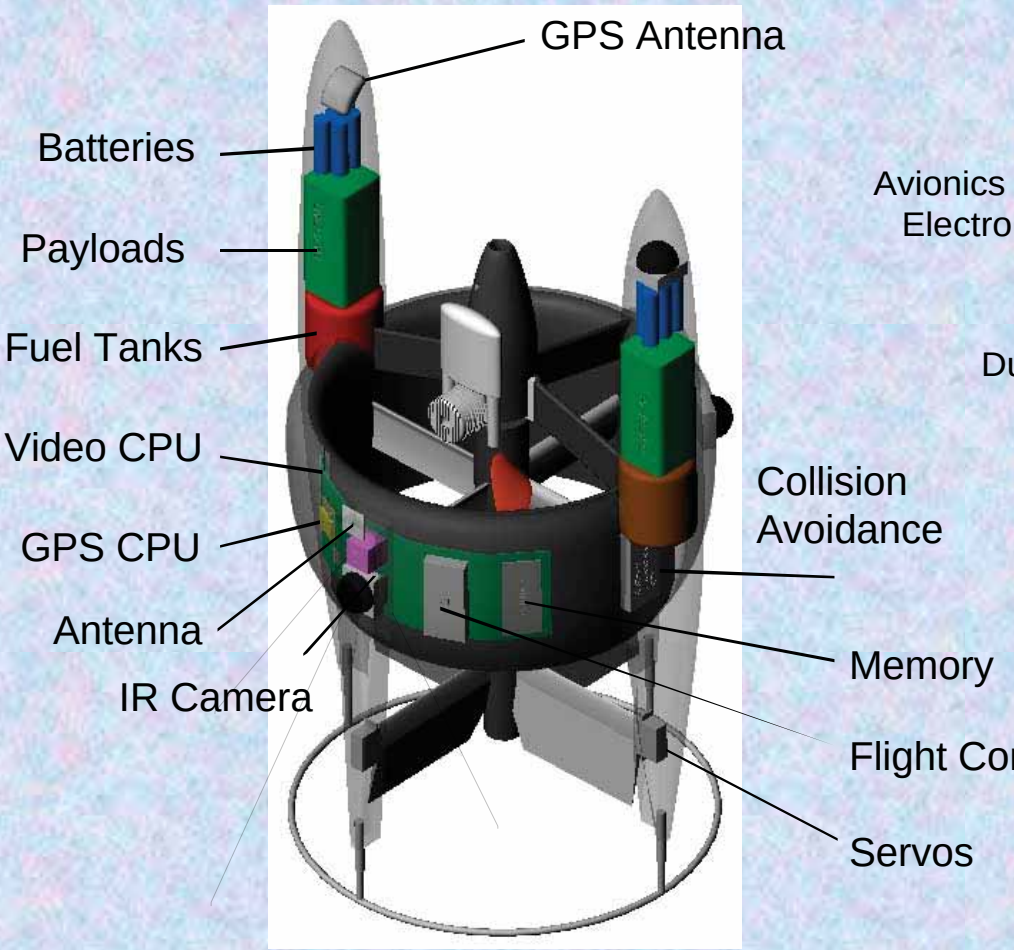
- **Flight Speeds**
  - *Max. demonstrated flight speed in hover mode: 22 kts*
  - *Max. predicted flight speed transitioned flight mode: 88 kts*
  - *Min. turn radius (for maneuvering): 0 ft*
  - *Max. rate of climb demonstrated at 0 kts forward speed: 4800 fpm*
  - *Max. controllable rate of descent demonstrated: 1700 fpm*
- **Endurance**
  - *Max. predicted endurance with no payload: 34 minutes*
  - *Demonstrated endurance with mission package: 16 minutes*
- **Range**
  - *Max. hover-mode range predicted: 15 nmi (ferry range)*
  - *Max. transitioned range predicted: 50 nmi (ferry range)*

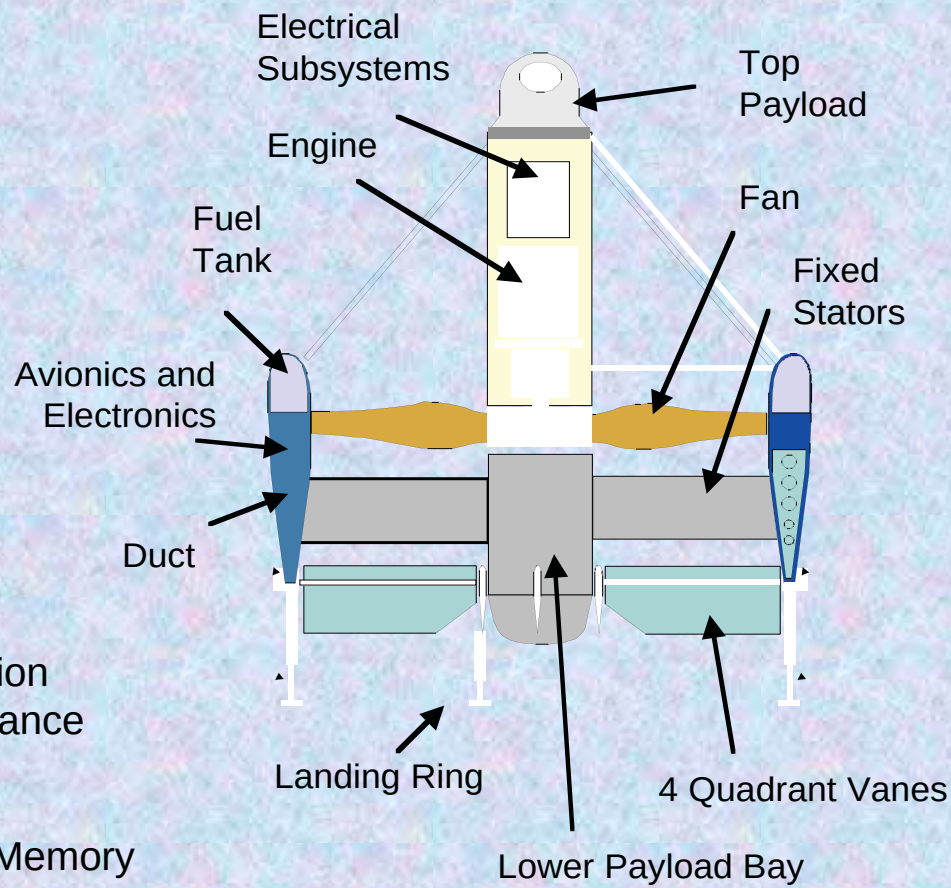


OAVs on the Battlefield



Ducted Fan UAV Inboard Profiles





AVID LLC

DARPA

Flight Proven Autonomous

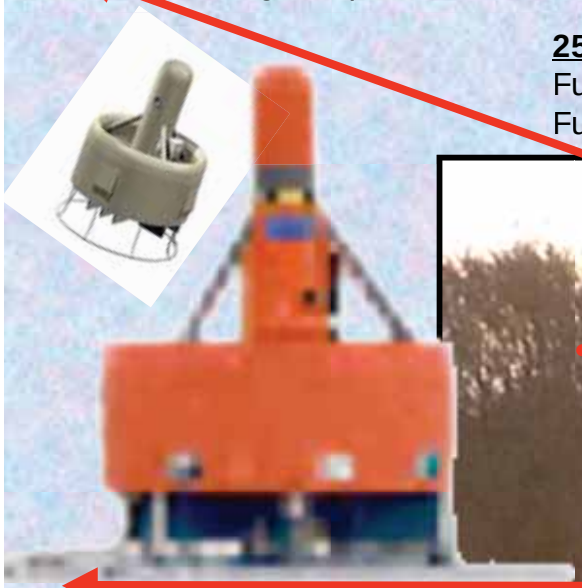
67" Fan Diameter
Hover and low speed flight testing completed

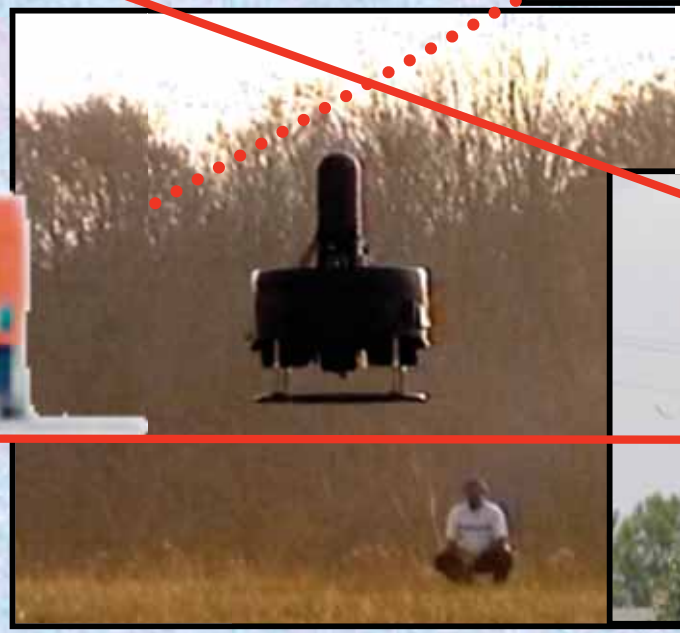
25" Fan Diameter
Fully autonomous flight
Full flight speed regime

31" OAV FCS Vehicle
- Low cost manufacturing
- Common components
- Full autonomy

11.5" Fan Diameter
Fully autonomous flight over full flight speed regime, field tested by Military in Hawaii

7" Fan Diameter
Successful hover, low speed & high speed transition





LARGE

MEDIUM

SMALL

MICRO

Scalable Solution = family of vehicles

Class I

ARMY FCS

- AVID Supports Honeywell in Contributing Aircraft Design and Analysis and Propeller Design and Analysis
- AVID is part of a larger team for Honeywell including AAI, Locust, Techsburg

AVID Tools and Expertise

- AVID lead for aerodynamic design through PDR
- AVID designing fan for performance and acoustics
- Configuration CFD using TetRUSS and FUN3D
- Performance in AVID OAV

Status

- Concept design is underway
- Wind tunnel testing to happen in first months of 2008
- First flight in 2009