Automatic Aircraft Configuration Redesign

The Application of MDO Results to a CAD File

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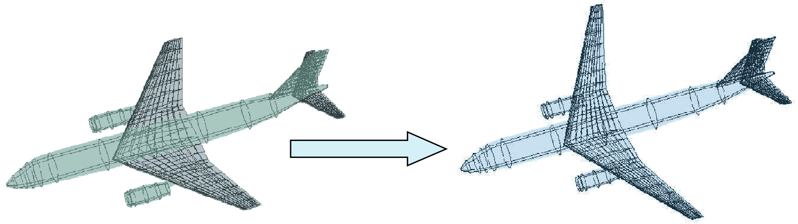
Overview

- Integration of MDO with design layout CAD to automatically revise the design layout to match optimization & sizing results
- Properly done, can significantly reduce the time to complete a design iteration ("Dash-1" to "Dash-2")
- Can't be perfect, but can do most of the "grunt work"



- Company-funded effort, methods developed for and implemented into RDS-Professional aircraft design software

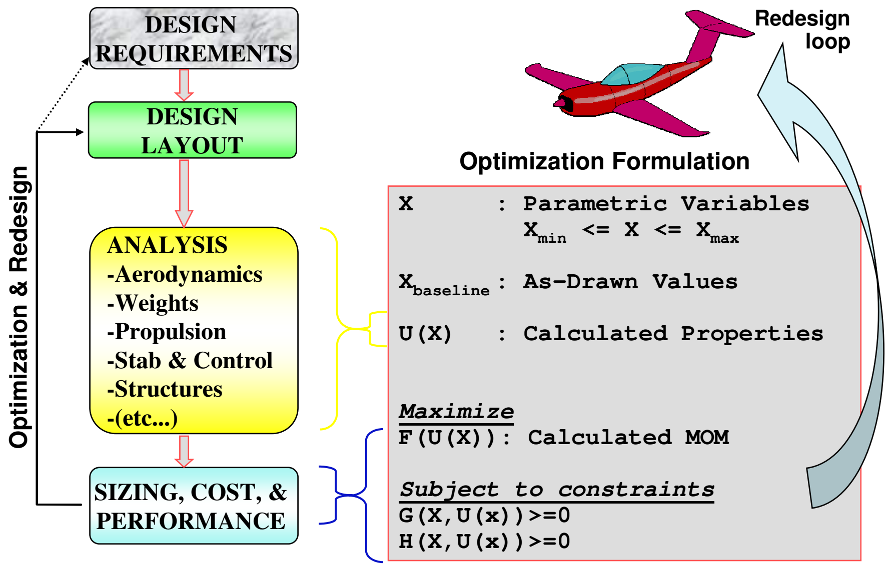
Approach

Two possible approaches:

1. **Revise CAD file *during* MDO**
    - Lets you recompute geometric analysis inputs during MDO
    - Time consuming and requires extensive setup
    - Probably needed for high-end CFD & structures FEM
2. **Revise CAD file *after* MDO**
    - Approximate effects of revised geometry on analysis inputs during MDO
    - Use final MDO result to revise CAD file
    - Quick, minimal setup with reasonable approximations
    - Must use types of analysis that are insensitive to details of geometry (classical aero methods, DATCOM, panel codes, statistical weights, etc…)

Second approach chosen to allow thousands of MDO iterations on a PC - and RDS uses such classical analysis methods

Conceptual Design & Optimization Process



RDS -Integrated Software for Aircraft Design & Analysis

•PC-based program for aircraft design, analysis, & optimization

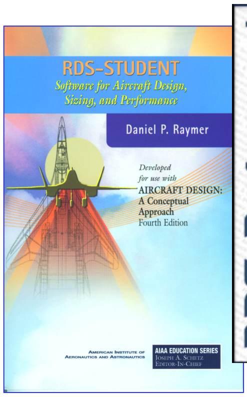
•20 Years of evolutionary development, 30,000+ lines of source code

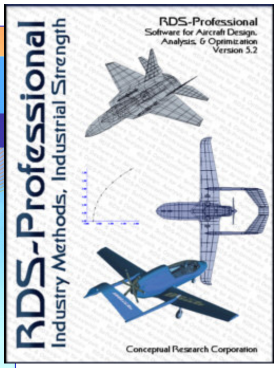
•Integrated CAD, aerodynamics, weights, propulsion (jet & prop), stability & control, sizing, range, performance, & cost analysis.

•Student & Professional versions in use world-wide

•Switch between MKS or FPS

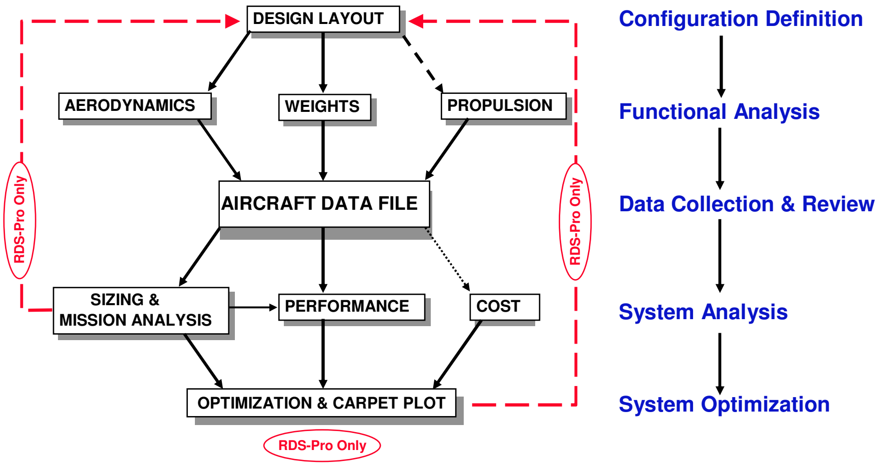
•Professional version adds automated trade studies, multivariable optimizer, greater accuracy, & numerous other "Design Pro" feature





Hard-wired for Aircraft Design & Analysis - NOT A SPREADSHEET!

RDS Auto-Redesign Loops

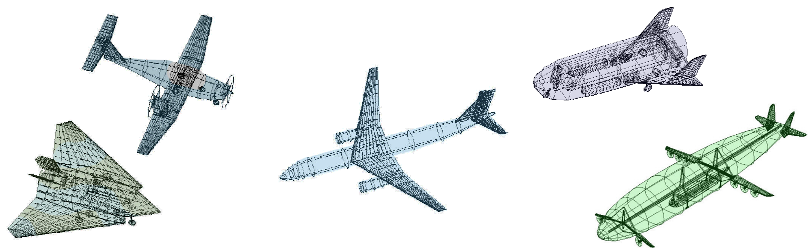


RDS Design Layout Module (DLM)

Numerous airplane-specific features and capabilities:

- **Quickly Create New Fuselage, Wing/Tail, Wheel, External Store, Engine, Seat, and many others, then reshape as desired**
- **Position, Scale, Stretch, Copy, Instance, & Mirror Components**
- **Reshape Wings & Derived Components by Revising Reference Wing Geometric Data**

Best Feature: RDS-DLM knows what an airplane is



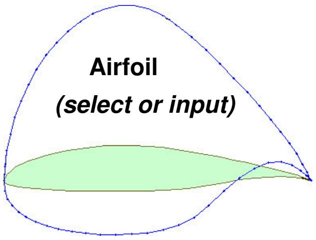
Trapezoidal Wing Creation

Area Sref	535
Aspect Ratio	3
Taper Ratio	0.2
Sweep (LE)	35
Sweep (c/4)	25.547
Airfoil	NACA 64-006
Thickness t/c	6%
Dihedral	-2
Incidence	0
Twist	0
Span	40.062
Root Chord	22.257
Tip Chord	4.451
Mean Chord	15.332
Y-bar	7.79
X loc (apex)	22.132
X loc (c/4)	31.42
Y location	0
Z location	0.7

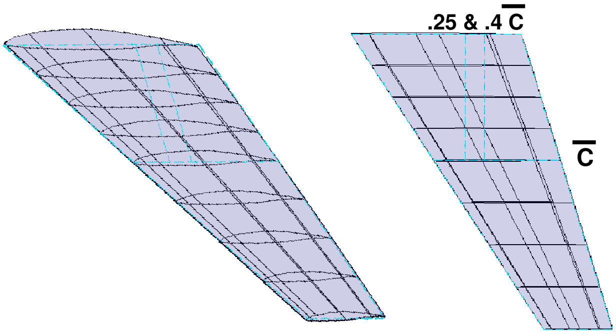
Area (Sref)
Aspect Ratio
Taper Ratio
Span
Root Chord
Tip Chord

Input three of these

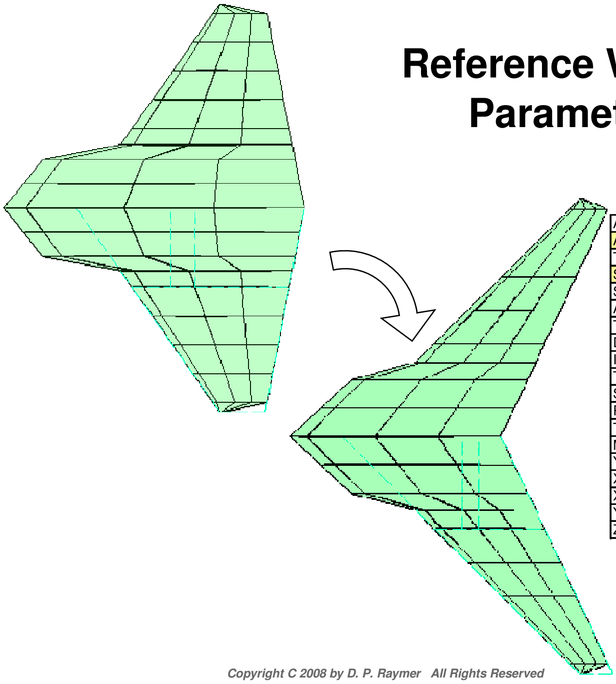
Airfoil
(select or input)



Then define these:
Sweep (any % chord)
Thickness t/c
Dihedral
Incidence
Twist



Reference Wing Redesign: Parameter Revision



Area Sref	535	535
Aspect Ratio	3	5
Taper Ratio	0.2	0.2
Sweep (LE)	35	45
Sweep (c/4)	25.547	40.914
Airfoil	NACA 64-006	NACA 64-006
Thickness t/c	6%	6%
Dihedral	-2	-2
Incidence	0	0
Twist	0	0
Span	40.062	51.72
Root Chord	22.257	17.24
Tip Chord	4.451	3.448
Mean Chord	15.332	11.876
Y-bar	7.79	10.057
X loc (apex)	22.132	18.394
X loc (c/4)	31.42	31.42
Y location	0	0
Z location	0.7	0.7

Extended SAWE8 Group Weight Statement Component Categories

Used to identify component types for weights analysis and geometry listings

- 002-000:Ref Wing
- 002-001:2nd Wing
- 002-002:BiplaneWing2
- 002-003:LEX
- 002-004:Winglet
- 002-005:Wing Strut
- 002-006:WingStruct
- 002-999:Wing-Other
- 008-000:Aileron
- 008-001:Elevon
- 009-000:Spoiler
- 010-000:Flaps(TE)
- 011-000:Flaps(LE)
- 012-000:Slats

- 031-000:Fuselage
- 031-001:Canopy
- 031-002:Fairing/Pod
- 031-003:InletFairing
- 031-004:Tailboom
- 031-005:2nd Fuselage
- 031-006:Door
- 031-007:Speed Brake
- 031-008:Body Flap
- 031-009:Payload Bay
- 031-010:Bay-Other
- 031-011:PassngerComp
- 031-012:Structure
- 031-999:Fuslag-Other

- 080-999:MiscFltCntrl
- 081-000:CockpitCntrl
- 082-000:AutoFltCntrl
- 083-000:SystemCntrls
- 084-000:Aux Power
- 085-000:Instruments
- 086-000:Hydraulics
- 087-000:Pneumatics
- 088-000:Electrical
- 090-000:Avionics
- 090-001:Antenna
- 091-000:AvionicInstl
- 092-000:Armament
- 094-000:Accomodation

(Partial listing)

Multidisciplinary Optimization (MDO*)

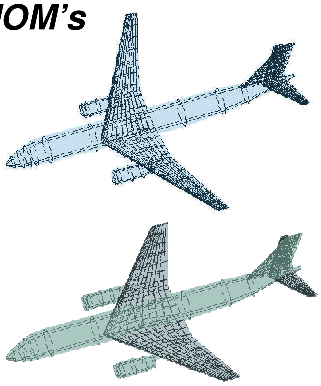
Multi*variable* design optimization of systems across widely different functional *disciplines*

"A methodology for design of complex engineering systems that are governed by mutually interacting physical phenomena and made up of distinct interacting subsystems" ...suitable for systems for which "in their design, everything influences everything else"

(J. Sobieski, NASA-Langley)

(*also Multidisciplinary *Design* Optimization)

RDS Design Variables and MOM's



THE BASIC SIX OR FIVE

- *T/W (unless fixed-size engine)*
- *W/S (aircraft weight / wing area)*
- *Aspect Ratio (span^2/ wing area)*
- *Taper Ratio (tip chord / root chord)*
- *Wing Sweep (leading edge)*
- *Airfoil t/c (thickness / chord)*

WING DESIGN

- *Design C_L (lift coefficient)*

FUSELAGE

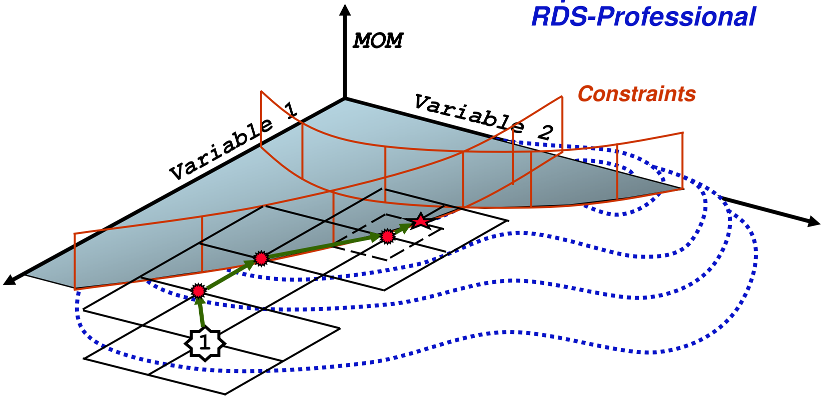
- *Length / diameter ratio*

Measures of Merit:

- **Wo**
- **We**
- **Wf**
- **Dvt Cost**
- **LCC**

Orthogonal Steepest Descent Deterministic Stepping Search

Implemented in RDS-Professional



RDS OSD MDO Typical Results

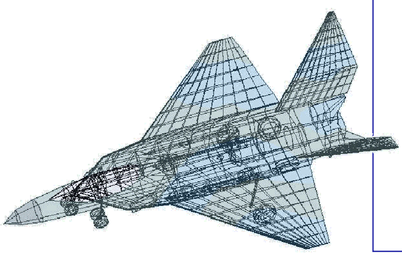
RDS-Professional MULTIVARIABLE OPTIMIZER RESULTS (20106 planes checked)

	REQUIRED	BASELINE	BEST
InstTurn	20.0	25.8	26.7
Ps@n=5	0.0	53.5	107.9
Ps@n=1	0.0	30.7	44.8
Accel	30.0	24.3	30.0
Takeoff	2000.0	1218.4	1285.6
Landing	2000.0	2192.3	1997.2

MEASURE OF MERIT: PRICE

Search step size = .03125

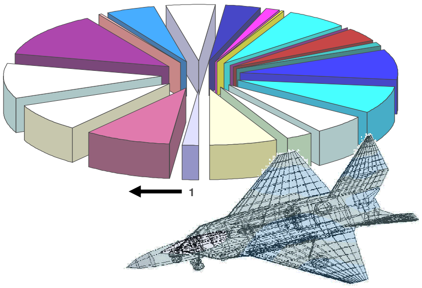
	BASELINE	BEST
T/W	0.726	0.617
W/S	76.3	68.6
ASPECT RATIO	2.500	2.969
SWEEP	48.0	38.4
TAPER RATIO	0.120	0.096
WING t/c	0.045	0.054
Fineness Ratio	13.8	16.6
CL-design	0.200	0.235
Sized Wo	44812.4	36381.0
Sized We	23804.6	19803.9
Sized Wf	17877.7	13447.0
Price	$ 38.67m	34.12m



RDS-Pro Only

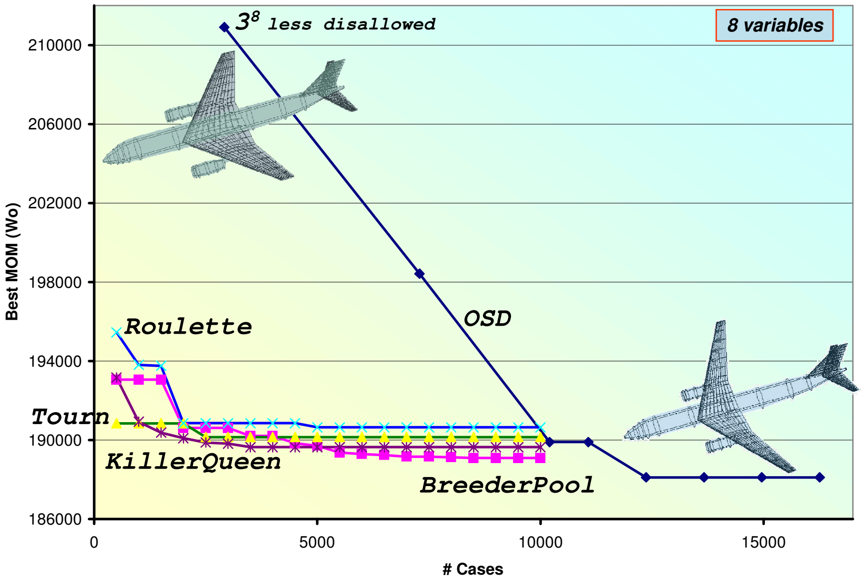
RDS Stochastic MDO (incl. Genetic Algorithm)

- MDO routines implemented into RDS framework using existing analysis input, mission, and performance constraint files.
- Methods include Monte Carlo, Evolutionary, and Genetic Algorithms, with numerous options for selection and crossover



Stochastic MDO not yet provided in release version of RDS-Pro since OSD gets better results in acceptable amount of time, given the number of variables (8) and the analysis methods employed

RDS MDO Results: Transport

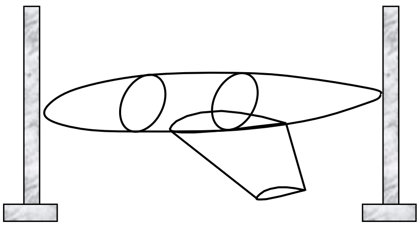


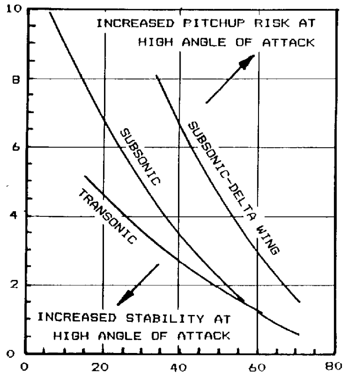
Aircraft Redesign Approximations During MDO

- •Thrust and fuel flow vary by thrust-to-weight ratio *(T/W)*
- •Wing area varies based on wing loading *(W/S)*
- •Tail areas vary by the 3/2 power of wing area to hold constant tail volume coefficient, also vary as fuselage length varies
- •Nacelle wetted area varies by *T/W*
- •Wing fuel volume varies by 3/2 power of wing area
- •Airfoil $C_{L\text{-}max}$ varies with *t/c* and design C_L using empirical regression of NACA airfoils
- •Airfoil leading edge roundness parameter (ΔY) varies with design C_L via camber approximation
- •A_{max} varies with change in wing area, *t/c*, and cos(sweep)
- •A_{max} adjusted for fuselage diameter as fineness ratio changes
- •Landing gear length changes proportional to length of fuselage

Not actually changing the CAD file during MDO

Geometric Constraints During MDO





Geometric Constraint Options:

- – Fuselage Length (maximum limit)
- – Fuselage Diameter (minimum limit)
- – Wing Span (maximum limit)
- – Constrain Aspect Ratio vs. Sweep for Pitchup
- – Hold *Net Design Volume*

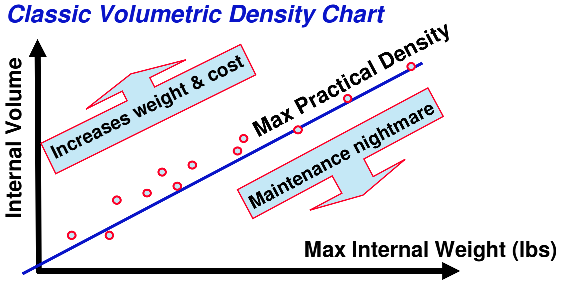
Design Realism: *Net Design Volume**

•Quick estimate of "un-spoken-for" volumetric density for structure, systems, access, growth….

•Concern: fuel volume in wing lost if higher W/S, lower t/c

•NDV density of baseline calculated, then held during MDO by scaling fuselage as vehicle scales & changes

Classic Volumetric Density Chart



*apparently original concept – ref. Raymer, D., *Enhancing Aircraft Conceptual Design using Multidisciplinary Optimization,* Swedish Royal Institute of Technology (KTH), Stockholm, Sweden, 2002

Net Design Volume Procedure

•Start with fuselage & wing volumes, total empty weight

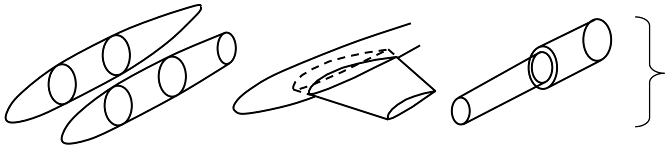
•Remove tails, pylons, external nacelles, canopy,...

•Subtract big and obvious volumes & weights

- Fuel
- Engine & ducts (if in fuselage)
- Payload, passenger, crew compartments

•NDV density is net weight divided by net volume

$$NDV = \{Vfus + Vwing\} - Vfuel - Vppc + \underbrace{Nengines\{Vnacelle - Veng - Vduct - Vtailpipe\}}_{\text{Ignore if separate nacelles}}$$



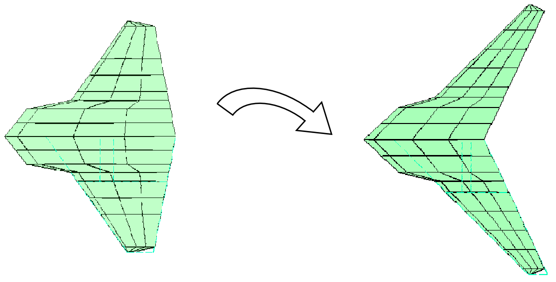
Simplified volume calculations for various aircraft components

Post-MDO Automatic Scaling Procedure

- Optimizer creates and saves “best airplane” parameters file with as-drawn and as-optimized values of:
  - Wo, T/W, & W/S
  - Wing Aspect Ratio, Sweep, Taper Ratio, & Thickness Ratio
  - Wing Design Lift Coefficient (defines goal for twist & camber)
  - Fuselage Fineness Ratio, Length, & Diameter
- After MDO, jumps back to CAD module to scale a copy of the design layout to match optimized values
- Extended SAWE8 codes used to determine appropriate scaling laws to apply to each component
- User is prompted for approval before each change
- User can accept, reject, or change entire design when done

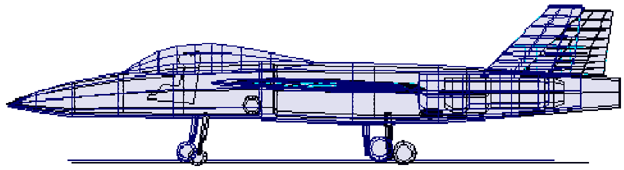
Post-MDO Automatic Scaling Laws (1)

- Whole design scaled to optimized & resized Wo
- Fuselage stretched to optimal fineness ratio holding NDV if used
- Wing scaled to optimal W/S & sized Wo plus optimized geometry
- Tails scaled to hold tail volume coefficient constant ($S \alpha W^{1.5}$)
- Other aero surfaces scaled proportional to wing area
- Components derived from wing or tail are also scaled to match
- All aero surface geometric parameter listings updated



Post-MDO Automatic Scaling Laws (2)

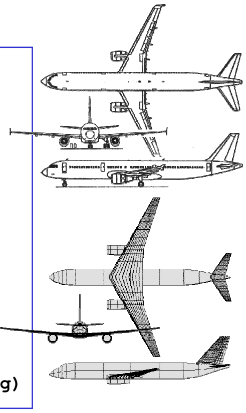
- Engines scaled to optimal T/W & resized Wo ($D\ \alpha\ T^{.5}$, $L\ \alpha\ T^{.4}$)
- Nacelles scaled to engine scaling
- Tires scaled statistically to Wo (width $\alpha\ W^{.45}$, diameter $\alpha\ W^{.32}$)
- Landing gear leg length adjusted to new fuselage length
- Landing gear leg cross section scaled (diameter $\alpha\ W^{.5}$)
- Ground plane & tipback angle scaled to new fuselage length
- Components not covered by a scaling law can be scaled proportional to weight change (lengths $\alpha\ W^{.333}$)
- Component locations revised to keep relative geometry



Typical Optimizer Results: Airbus A321

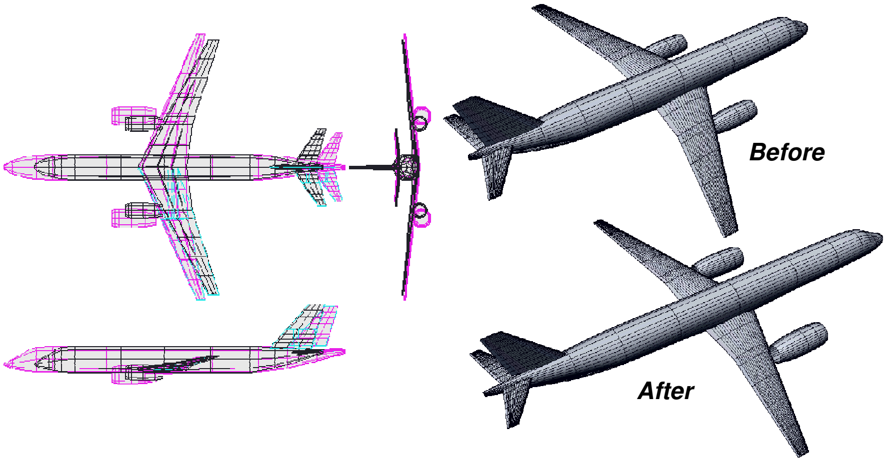
- Re-Optimize to M.95 Cruise (vs. M.8 baseline)
- Increases TOGW, increases T/W, makes wing thinner, increases aspect ratio, increases fuselage fineness ratio, reduces sweep (!)

As-Drawn	Best	
213844.2,	243260.2,	TOGW
0.3442,	0.4379,	T/W
127.8972,	153.4767,	W/S
10.1300,	11.6495,	A
29.0000,	23.2000,	Sweep
0.2500,	0.2000,	Taper
0.1200,	0.1080,	t/c
11.2658,	13.5190,	Fuselage Fineness Ratio
0.5500,	0.5500,	Design Lift Coefficient
145.9974,	164.8766,	Fuselage Length (pre-sizing)
12.9593,	12.1959,	Fuselage Diameter (pre-sizing)



Automatic Redesign Results: Airbus A321

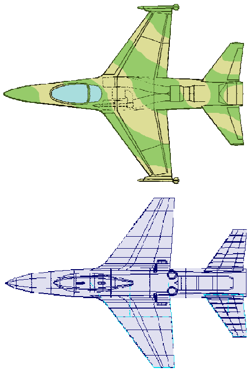
- 10 seconds of work after MDO results presented on screen
- Not perfect, but a good start on the "Dash-2" design



Typical Optimizer Results: DR-3

- Optimize Dash-1 to sizing mission and performance constraints
- Reduces TOGW, reduces T/W & W/S, makes wing thicker, reduces aspect ratio & sweep, increases fuselage fineness ratio

As-Drawn	Best	
16480.0,	14123.3,	TOGW
0.9800,	0.8820,	T/W
56.0544,	50.4490,	W/S
3.5000,	2.8000,	A
38.0000,	30.4000,	Sweep
0.2500,	0.2500,	Taper
0.0600,	0.0720,	t/c
8.2182,	9.8618,	Fuselage Fineness Ratio
0.4000,	0.4350,	Design Lift Coefficient
45.2000,	51.0449,	Fuselage Length (pre-sizing)
5.5000,	5.1760,	Fuselage Diameter (pre-sizing)



Automatic Redesign Results: DR-3

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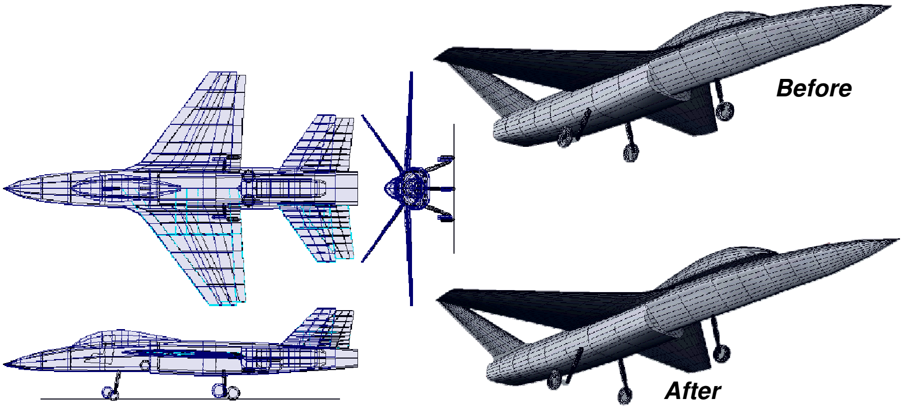

Conclusions

- Automatic Aircraft Configuration Redesign applies MDO results to a CAD File, modifying the design accordingly
- Auto-redesign is feasible, useful, and not too difficult to implement – but don't expect a perfect result !
- Requires a CAD system that "knows what an airplane is" and recognizes components by type using a scheme such as RDS's extended SAWE8 codes (can be integral, added, or scripted)
- If setup time for each design is excessive, benefits are lost and the user will just scale, stretch, and move components "by hand"