April 20, 2010

NASA N+3
Subsonic Ultra Green Aircraft Research
SUGAR
Final Review

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BR&T Deputy

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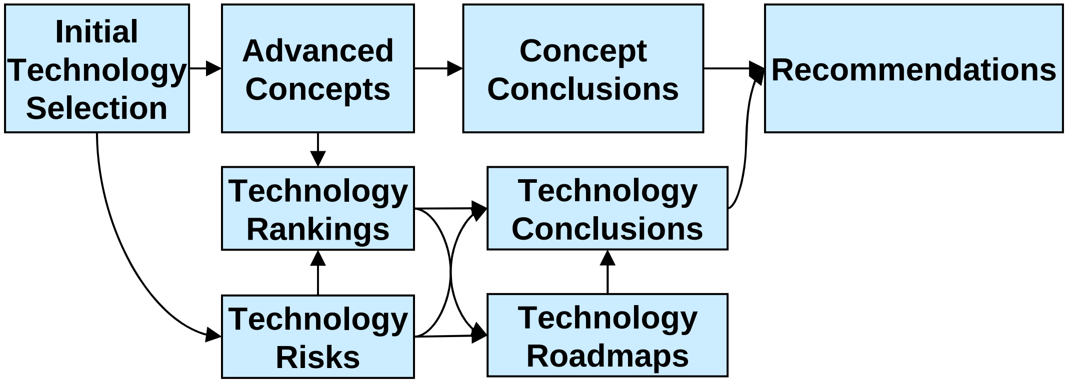
SUGAR Phase 1 Final Review

BCA – Advanced Concepts BR&T – Platform Performance Technology

8:00

- **Task Flow & Schedule**
- **Future Scenario, Concepts, & Technologies from the 6-Month Review**
- **Concept Performance and Sizing from 12-Month Review**
- **Technology Activities**
  – Risk Assessment / Rankings / Roadmaps
- **Summary, Conclusions, and Recommendations**
- **Lunch**
- **Proprietary Session**



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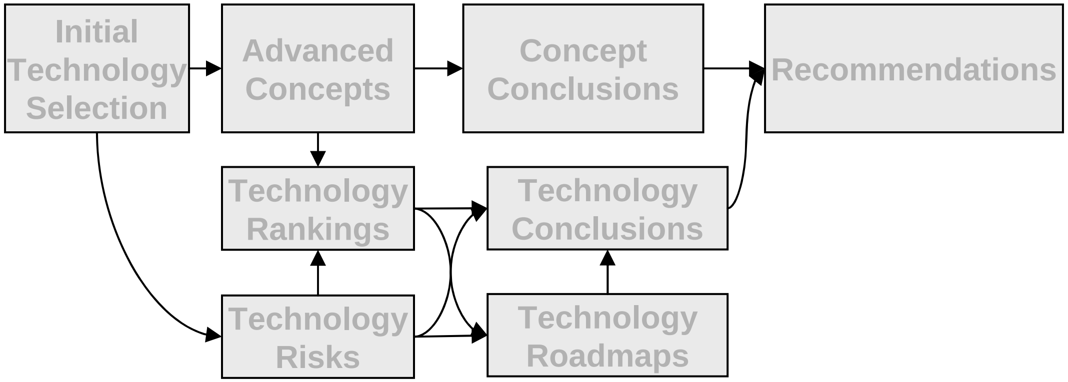
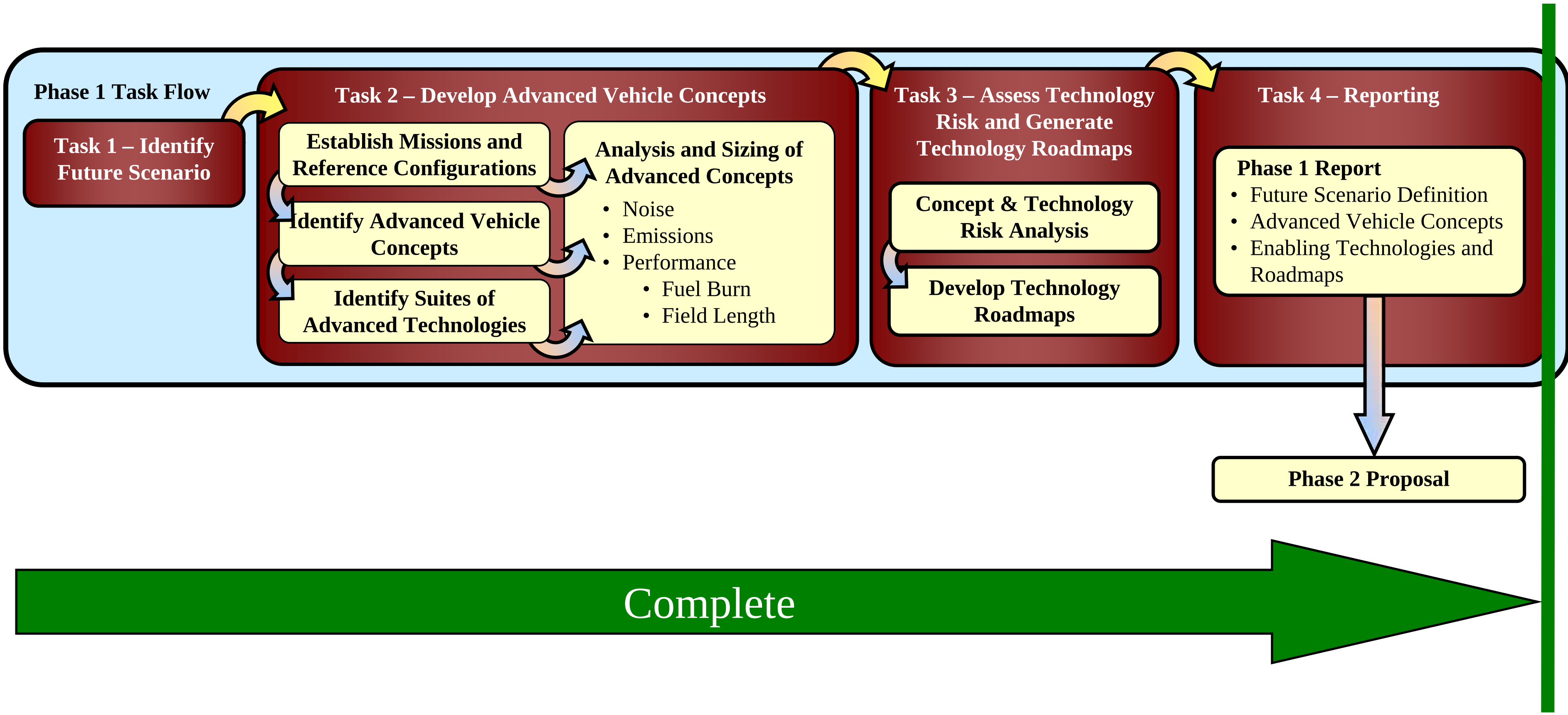


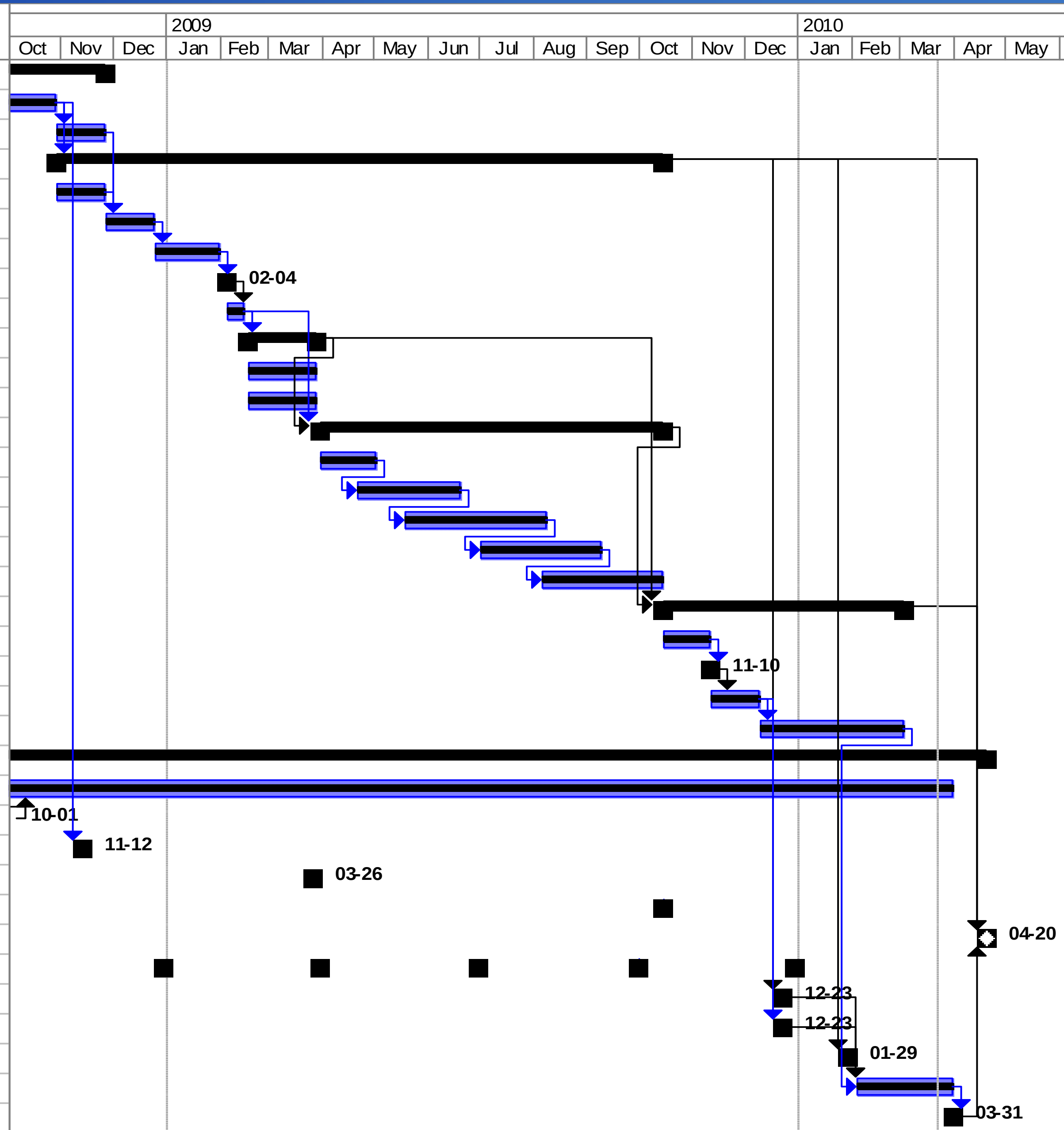
SUGAR Study - Task Flow Chart



Study structured to provide data to make good technology decisions

Phase 1 SUGAR Project Is Complete

ID	Task Name
1	**Task 1-Develop Future Scenario**
2	Develop 1st Draft
3	Refinement
4	**Task 2 - Develop Adv. Vehicle Concepts**
5	Establish Reference Configuration Vehicles
6	Establish Reference Missions
7	Workshop Preparation
8	Concept Workshop
9	Identify Advanced Vehicle Concepts
10	**Identify Suites of Advanced Technologies**
11	Propulsion Technologies
12	Aircraft Technologies
13	**Analysis and Sizing of Concepts**
14	2008 Baseline (SUGAR Free)
15	2030 Reference (Refined SUGAR)
16	Advanced Concept 1 (SUGAR High)
17	Advanced Concept 2 (SUGAR Volt)
18	Advanced Concept 3 (SUGAR Ray)
19	**Task 3 - Technology Planning**
20	Workshop Preparation
21	Technology Planning Workshop
22	Assess Technology Risk
23	Generate Tech. Roadmaps
24	**Task 4 - Coordination, Management, and Reporting**
25	Coordination and Management
26	Contract Start
27	Kick-Off Meeting
28	6-Month Review
29	12-Month Review
30	Final Review
31	**Quarterly Reports**
37	Trade Studies and Analysis Report
38	Technical Risk Assessment Reports
39	Advanced Concepts Configuration
40	Final Report Preparation
41	Final Report Delivered



SUGAR Phase 1 Final Review

8:05

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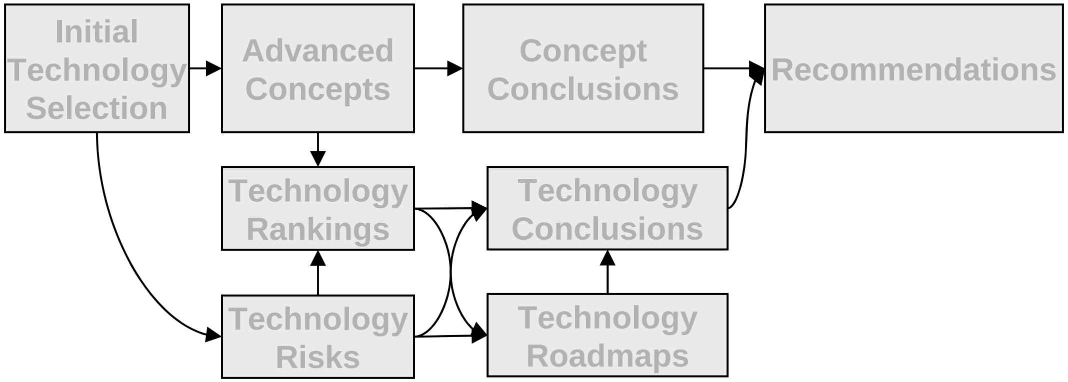
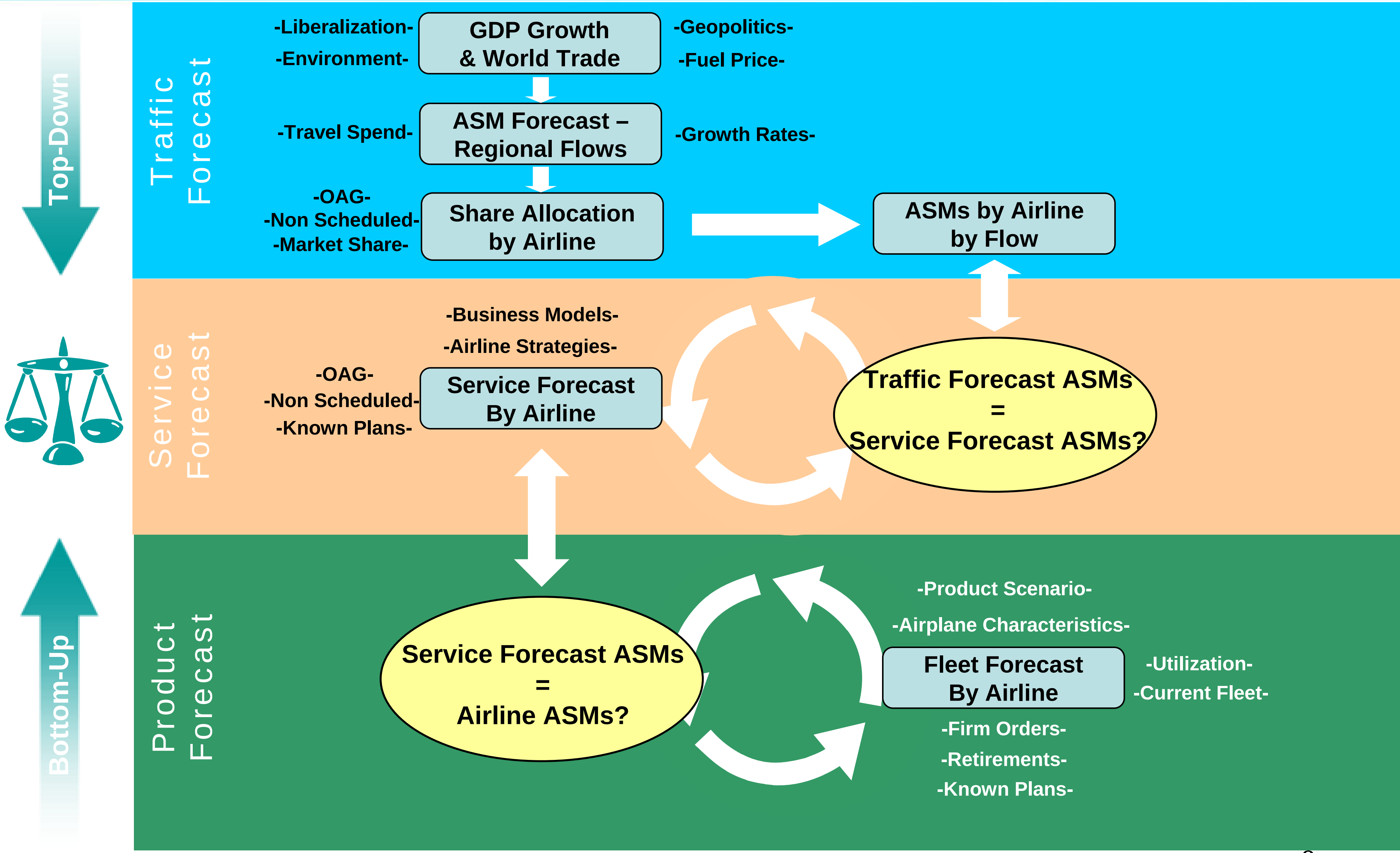


Current Market Outlook (CMO) Annually Since 1964

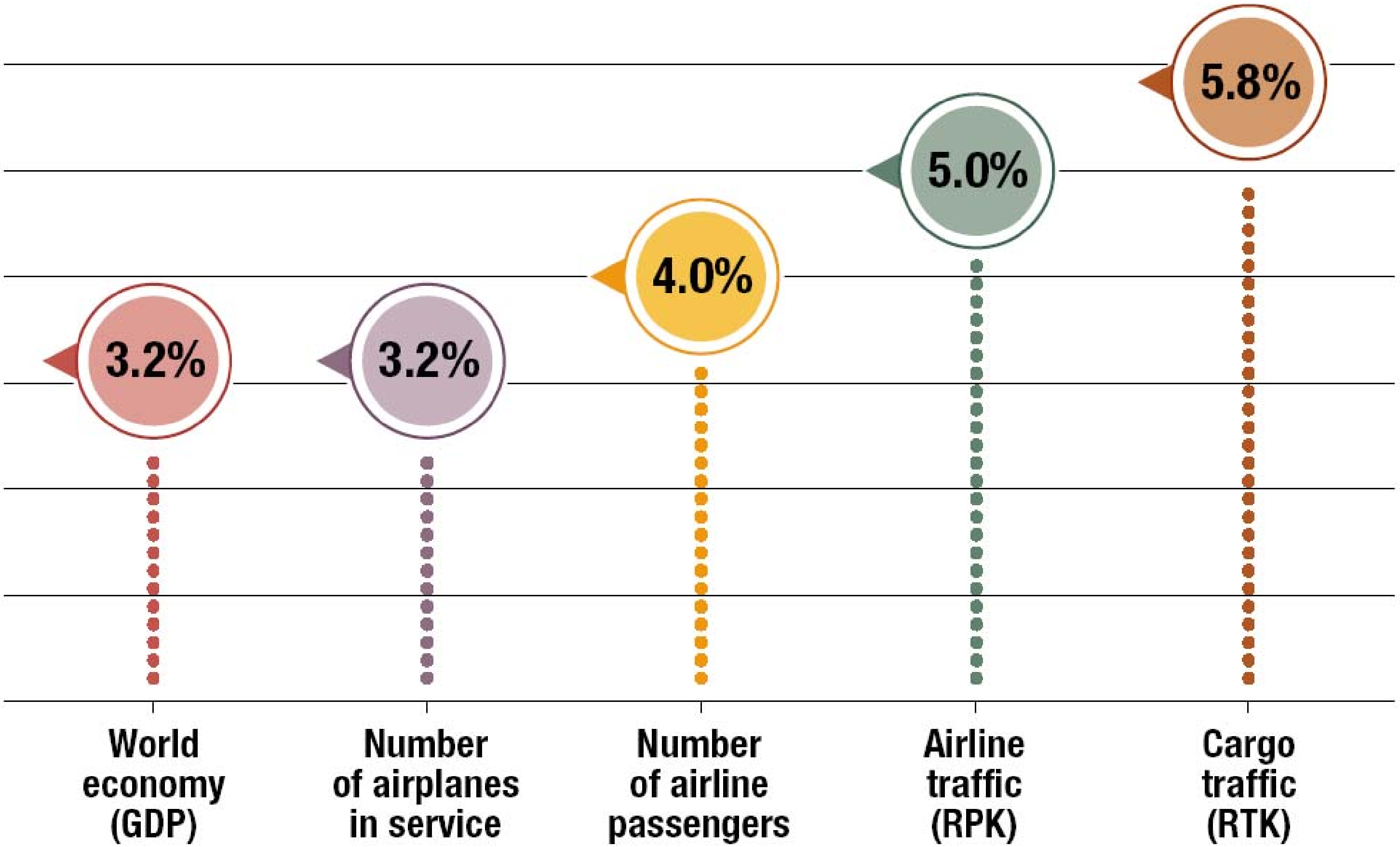
- For over 40 years, Boeing has published its 20-year forecast of the world demand for air travel and commercial airplanes
- The Outlook has been shared thousands of times with airlines, journalists, bankers, investment analysts, governments, suppliers, and educators
- The Boeing Current Market Outlook is the only complete forecast that combines top-down and bottom-up analysis
  - All jets 30 seats and over
  - Freighters
  - All regions of world
  - Scheduled and Nonscheduled flying

Future Scenario

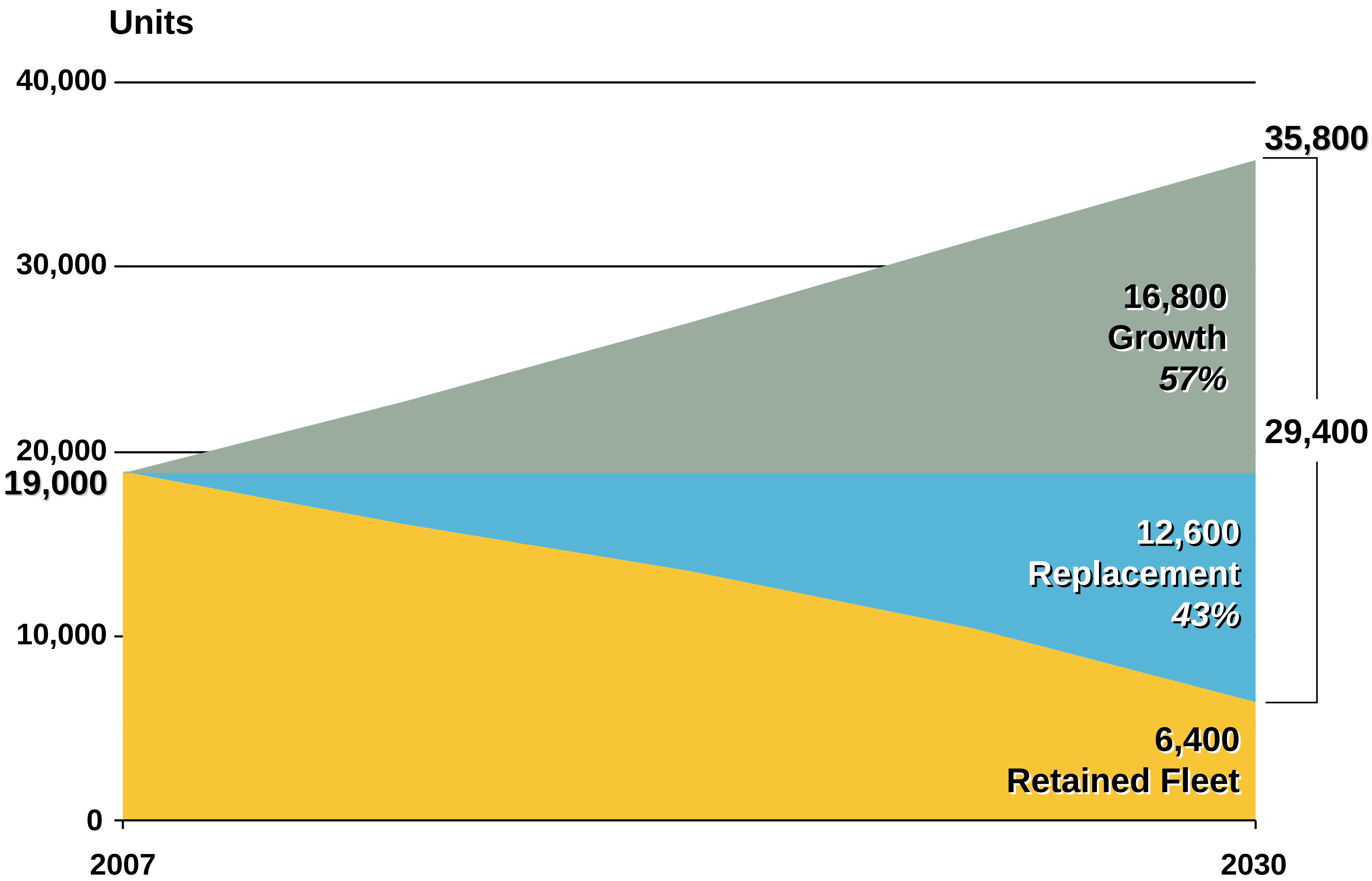
CMO Process Outline



2010-2030 forecast: strong long-term growth



Increasing demand for replacing older, less efficient aircraft



Aircraft Class Definitions

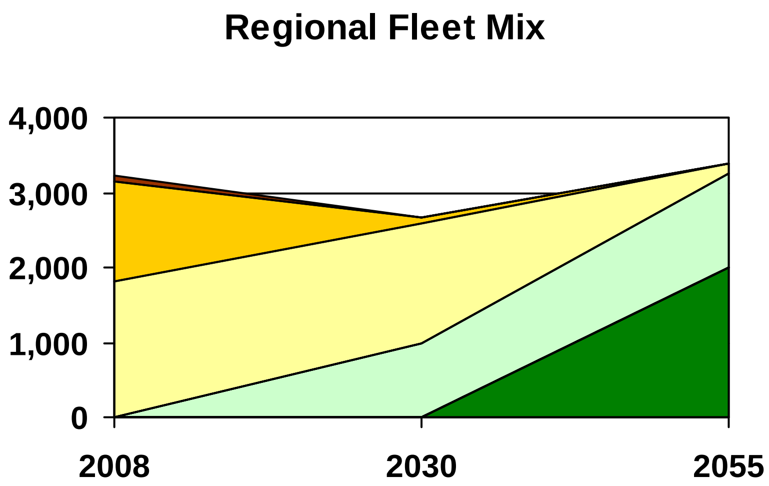
"N+3" Contract Classification

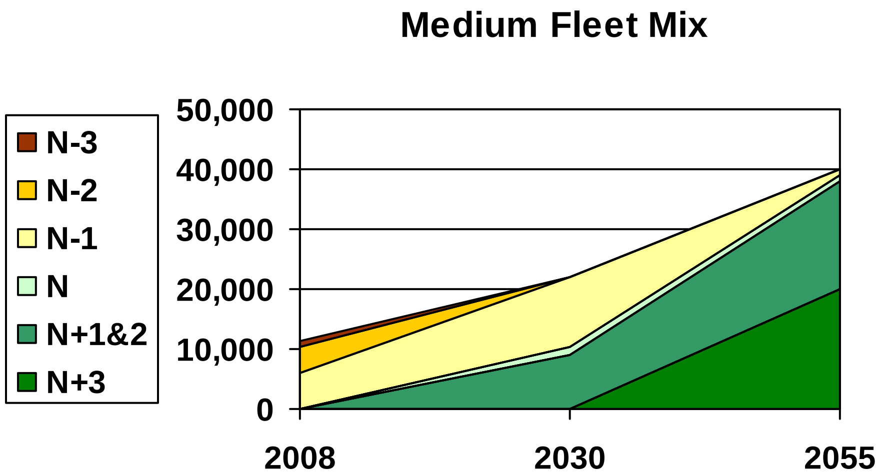
- Regional
- Medium
- Large

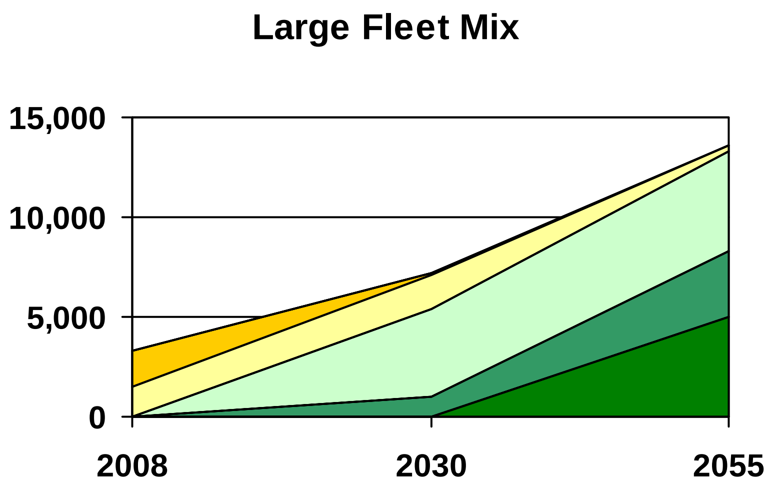
- **Boeing Classification**
  - **Regional**
  - **Single Aisle**
    - 737
    - 757
    - A320
  - **Twin Aisle**
    - 767
    - 777
    - A340
  - **Very Large Jets**
    - 747
    - A380
  - ~~**Freighters**~~ Not included in this study

All vehicles sized for this contract will be considered family center points

Aircraft Type World Fleet Mix Details







N+3 aircraft do not approach 50% of fleet mix until ~2055

Scenario Derived Payload-Range Req.

2030 Fleet			
	Regional	**Medium**	**Large**
Number of Aircraft	2,675	22,150	7,225
Family Midpoint # of Seats	**70**	**154**	**300**
Avg. Distance	**575**	**900**	**3,300**
Max Distance	**2,000**	**3,500**	**8,500**
Avg. Trips/day	6.00	5.00	2.00
Avg. MPH	475	500	525
Fleet Daily Air Miles (K)	8,500	100,000	55,000
Daily Miles	3,200	4,500	7,600
Daily Hours	6.92	9.23	13.96

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What Speed to Fly?

- **Minimum Speed For Each Aircraft Class Determined by Future Scenario**
  - Minimum Speed Drivers:
    - Desired City Pairs
    - Flight Crew Rules
    - Aircraft Utilization
  - Current Class Speeds:
    - Regional: ~ 0.70 – 0.75 Mach
    - Medium: ~ 0.75 – 0.80 Mach
    - Large: ~ 0.80 – 0.85 Mach

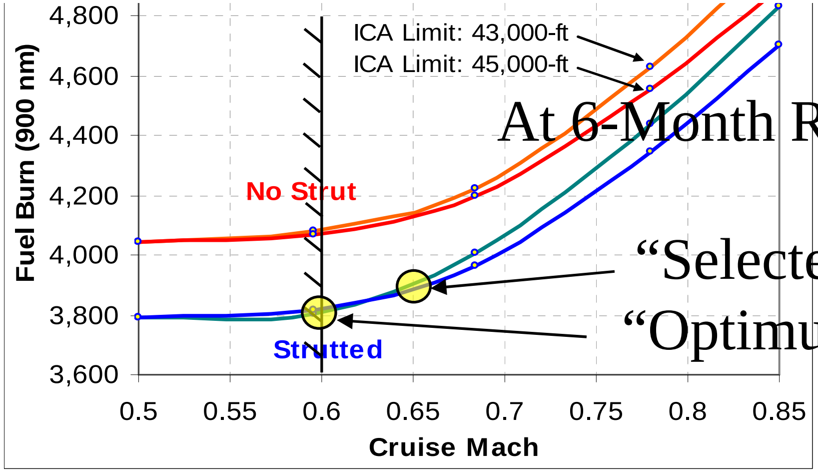
- **Propulsion technology may also place restrictions on speed**

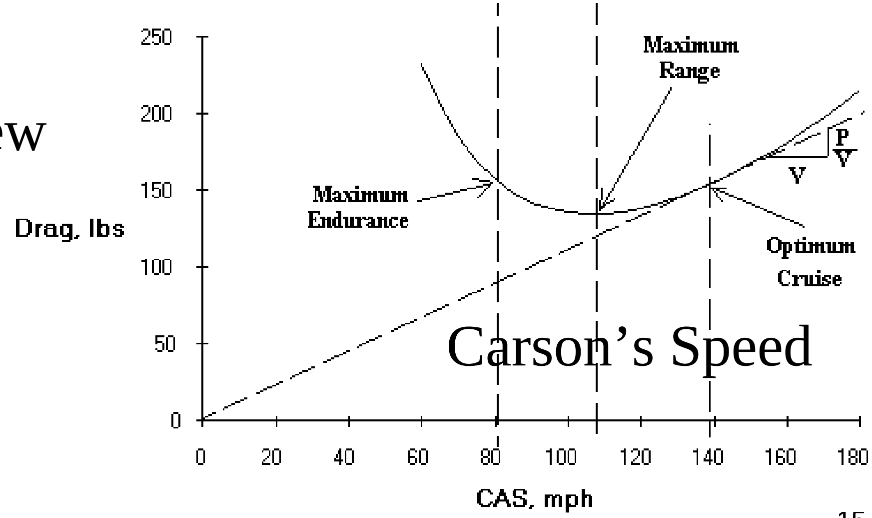
- **The SUGAR team has selected the "best" speed to fly above these MINIMUM Speeds projected by future scenario**

  - Regional: Optimum
  - Medium: 0.6-0.7 Mach
  - Large: 0.80 Mach

Action Item #5 from 6-Month Review (1)

- **Look at using "Carson's Speed" for selecting cruise Mach – use tangent point of fuel burn vs. cruise Mach plot**
  - *There are a lot of ways to approach this.*
  - *At the 6-month review, an "eyeball" approach was used to identify a "shoulder"*
  - *Carson's method assumes a relative value of fuel burn compared to speed –results in a speed of Mach ~0.8, which is not compatible with NASA fuel burn goals*
  - *For SUGAR, we have a goal to minimize fuel burn – which can result in an "optimum" cruise speed that is the "minimum" cruise speed of Mach 0.6*
  - *We are assuming that when a more sophisticated model that includes the value of speed, that the optimum speed will increase*



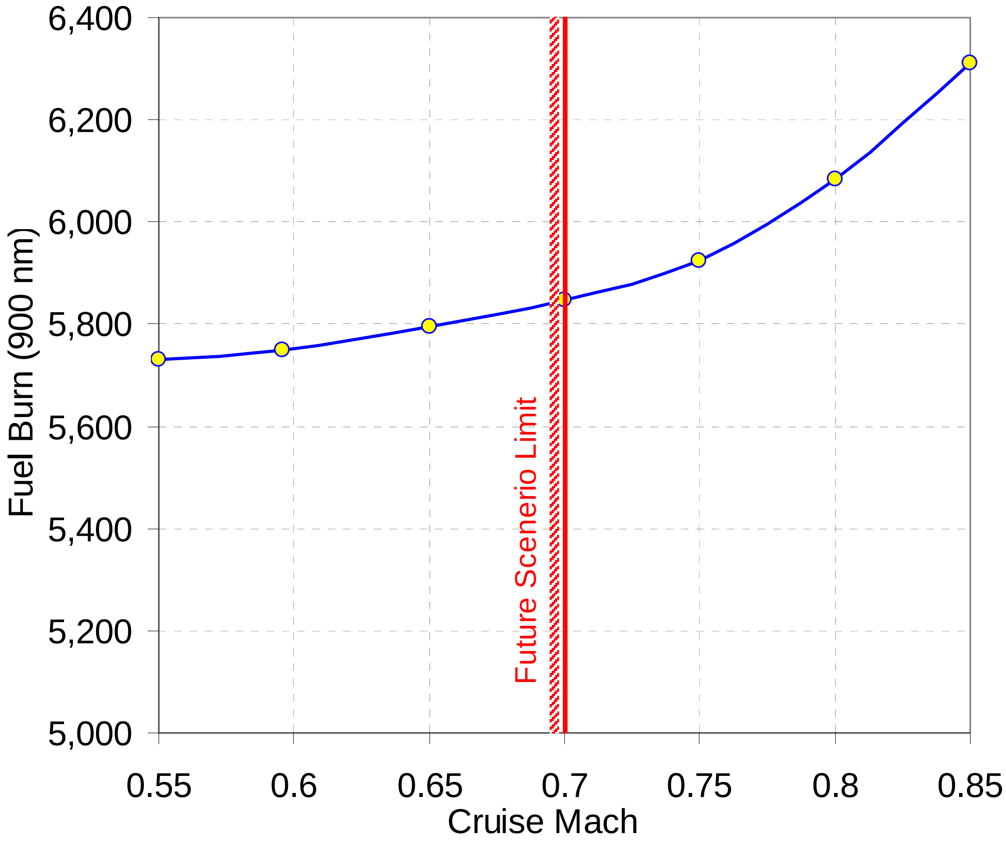


Action Item #5 (2)
Cruise Mach Selection Considerations

- **NASA fuel burn goals drive the speed to Mach 0.7 and then lower with diminishing returns**
- **Future Scenario work sets a lower limit of 0.7 (soft) and 0.6 (hard), based on city pairs, efficient aircraft utilization, and value of time in the markets (for medium size aircraft)**
- **Simple economic analysis drives the speed up as high as 0.8 for cheap fuel or as low as 0.7 for expensive fuel**
- **Gate-to-gate time improvements resulting from improved ATC, can compensate for decreases in cruise Mach**
  - 3500 nm cruise Mach can be as low as 0.69
  - 900 nm cruise Mach can be as low as 0.53

Action Item #5 (3) Cruise Mach Selection

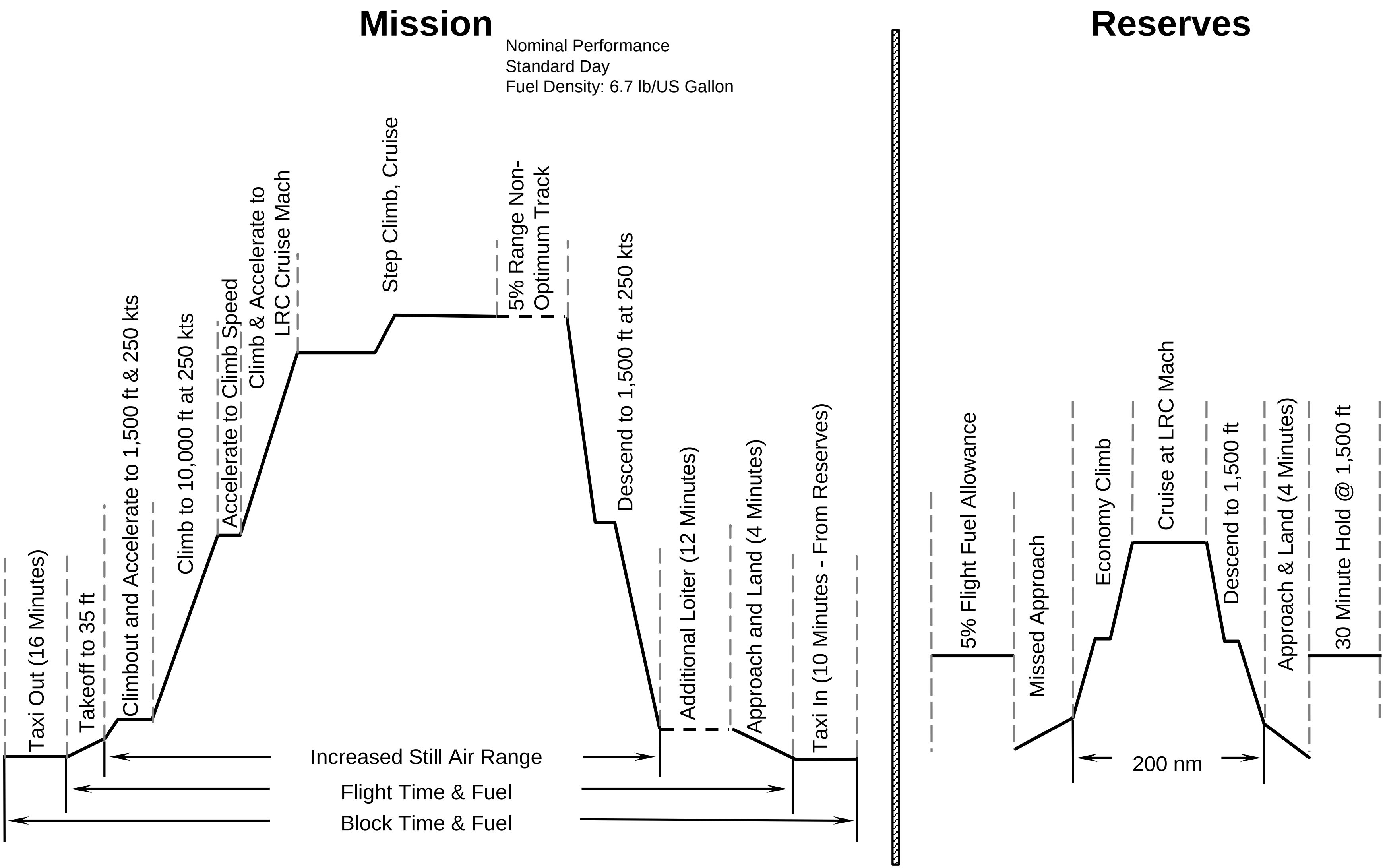
- **If only the NASA fuel burn goal is considered, we would choose Mach 0.6**
- **However, Future Scenario and economic considerations make it clear that a higher cruise Mach of 0.7 will be preferred and provides the best balance with NASA fuel burn goals**



- **We have quantified the impact of lowering the cruise Mach to 0.6 (and increasing to 0.85) as a sensitivity.**

‘N’ Reference Mission

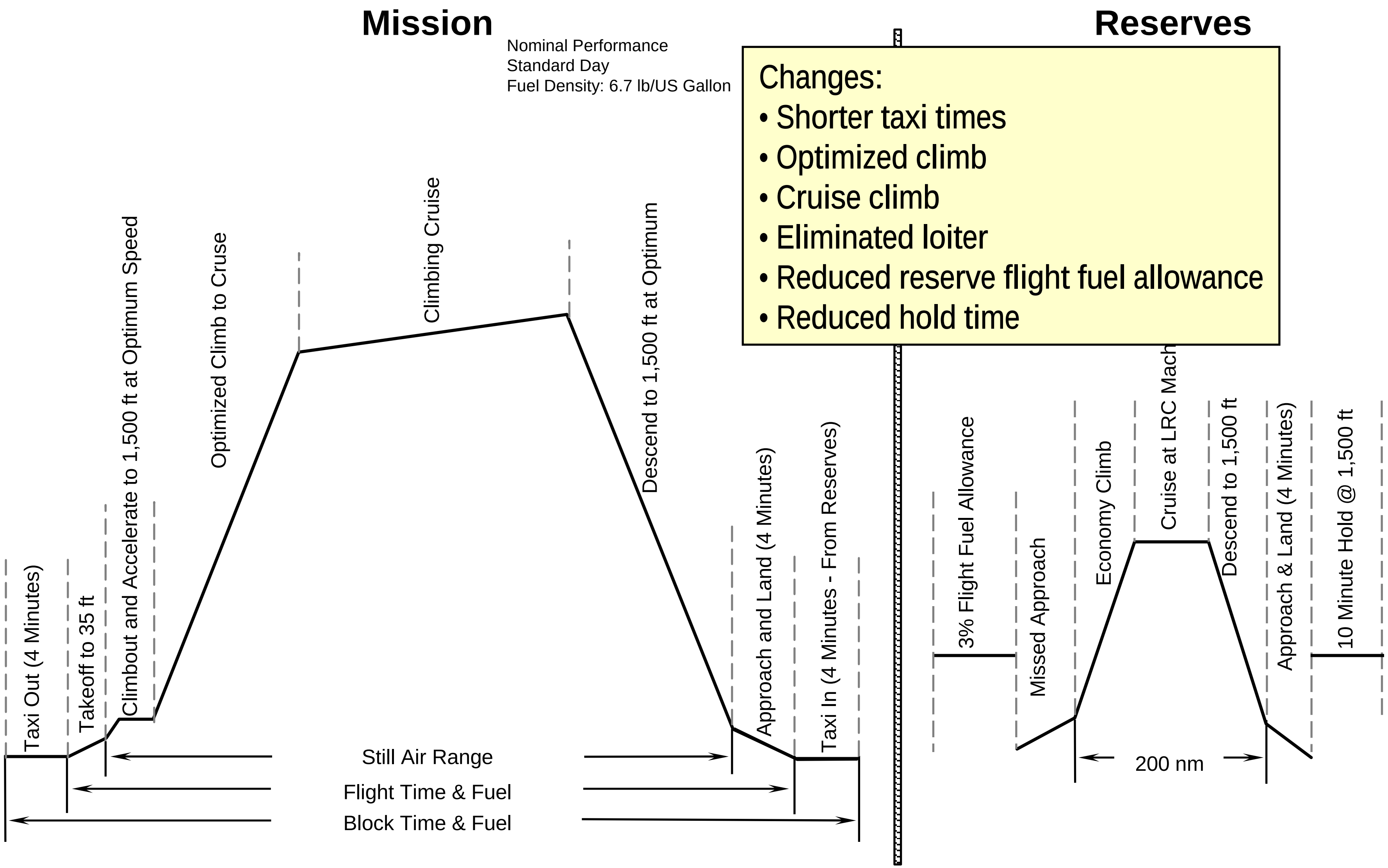
BCA – Advanced Concepts | BR&T – Platform Performance Technology



‘N+3’ Reference Mission

BCA – Advanced Concepts

BR&T – Platform Performance Technology



Changes:
- Shorter taxi times
- Optimized climb
- Cruise climb
- Eliminated loiter
- Reduced reserve flight fuel allowance
- Reduced hold time

Vehicle Layout Constraints

BCA – Advanced Concepts

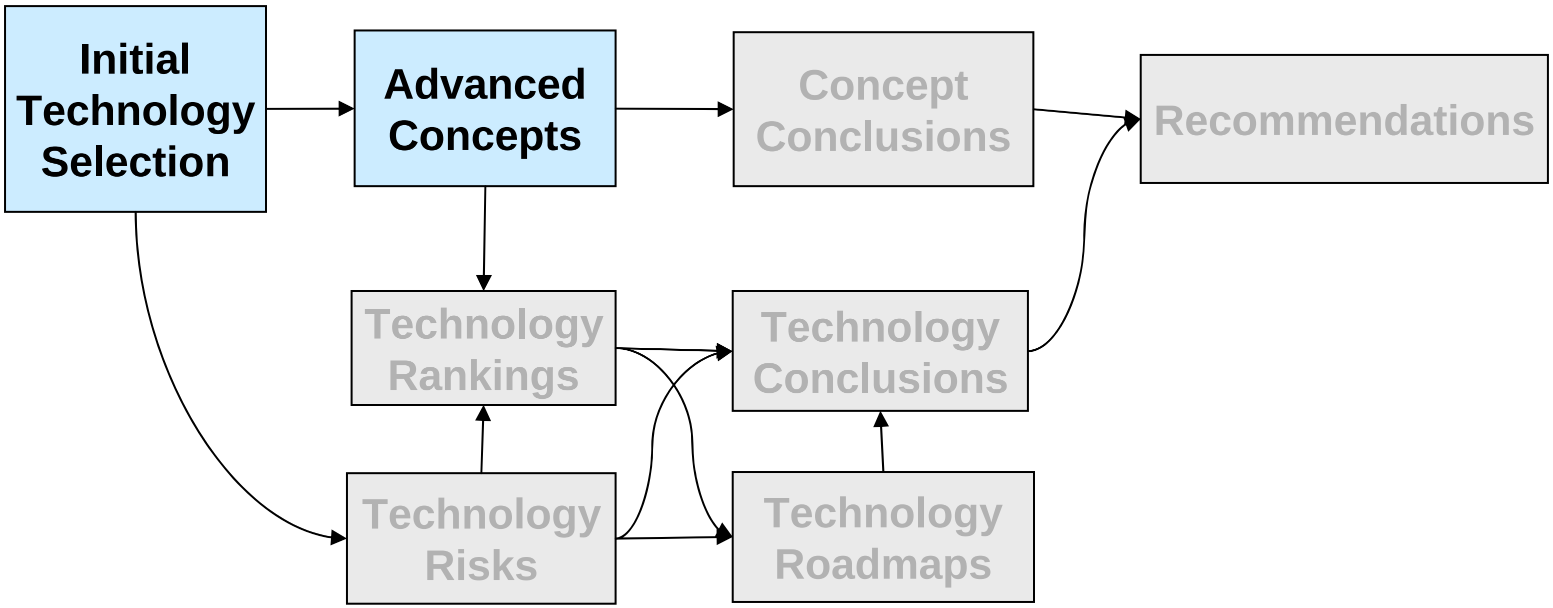
BR&T – Platform Performance Technology

		"N" Baseline	"N+3" Reference	"N+3" Advanced
Max Span	Regional	79 ft		(Folding if larger than gate)
	Medium	118 ft		
	Large	262 ft		
Propulsion System		Turbofan	Advanced Turbofan	Unconstrained
Configuration		Conventional		Advanced
Fuel		Liquid Hydrocarbon		Unconstrained
Tail Strike Angle		Unconstrained		
Tail Down; Roll Angle		8°		

SUGAR Phase 1 Process

BCA – Advanced Concepts

BR&T – Platform Performance Technology



Results of Configuration Workshop

February 2009

SUGAR Concept Workshop Overview

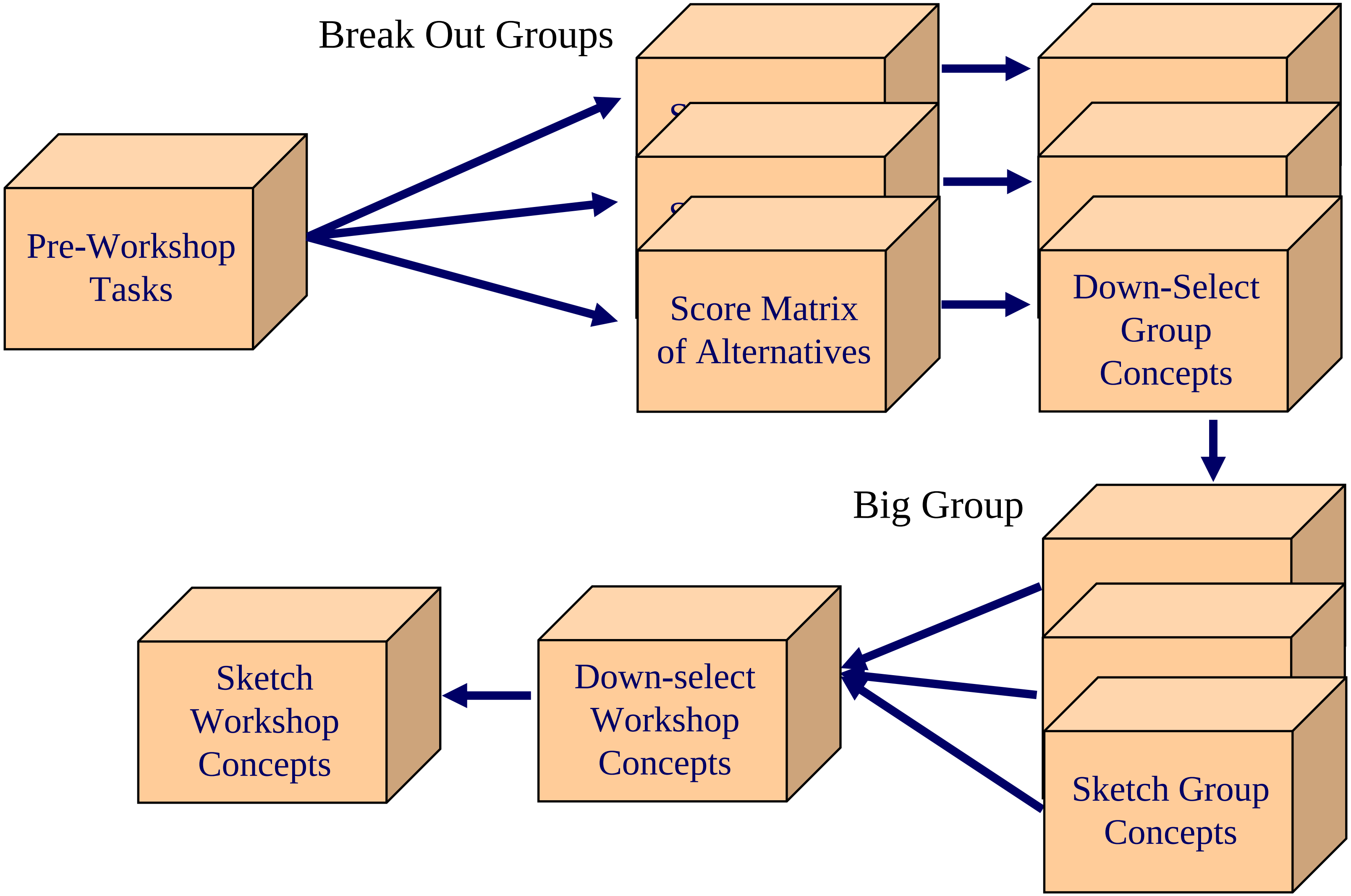
- The overall goal of the workshop was to downselect a few operational, airframe, and engine concepts for further analysis and study
- In preparation, possible concepts were brainstormed by Boeing and GE. These were evaluated based on their contribution to the overall NASA N+3 goals
- This information was compiled into an Interactive Reconfigurable Matrix of Alternatives (IRMA) that allowed for real time concept generation to occur at the workshop

			Metrics Selection		Alternatives (First)												
			Fuel Burn & Energy Consumed	Order of Selection	Alternative #1	Score	Select	Alternative #2	Score	Select	Alternative #3	Score	Select	Alternative #4	Score	S
Vehicle Characteristics	Fuse	Number of Fuselages	None		0		Yes	1			2					
		Wing-Body Blend	None		None			Fairing			Moderate Blend			Extreme Blend		
		Passenger Decks	None		1			1.5			2					
	Wing	Number	High	3	1			2								
		Location	Med	9	Low			Mid			High			Pylon Mount		
		High Lift System	Low		Conventional			Triple Slotted Flap		Yes	USB			EBF		
		Bracing	Low		None			Strut			Cable			Truss		
		Join	Med	7	None			Tip			Mid			Box		
		Folding	Med	8	None			In Flight			On Ground					
		Morphing	Low		None			Planform			Variable Camber			Both		
		Winglet	High	2	None			Conventional			Raked			Feathers		
	S&C	Pitch Effecter	High	4	Conv. Horizontal			T-Tail			V-Tail			Canard		
		Yaw Effecter	Med	5	Conv. Vertical			V-Tail			H-Tail			Winglet		
		Roll Effecter	Med	6	Aileron / Spoiler		No	Wing Warping		Yes						
	Propulsor Integration	Location	Low		Low Wing			Mid Wing			Above Wing			Aft Fuselage		
		Propulsor Type	None		Propeler			Open Rotor			High BPR Fan			Ultra High BPR Fan		
		Propulsor Arrangement	High	1	Discrete			Distributed								
		Energy Conversion	Low		Brayton			Const. Vol. Combustion			Fuel Cell/Motor			Piston		
		Augmentation	None		None			Batteries			Fuel Cell			Brayton		
		Primary Fuel	None		Liquid Hydrocarbon			Gaseous Hydrocarbon			Hydrogen			Batteries		

SUGAR's IRMA

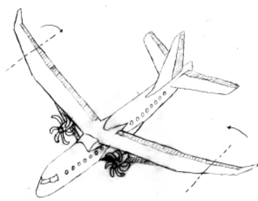
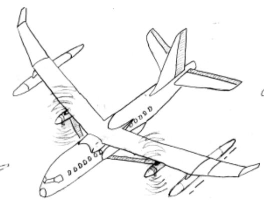
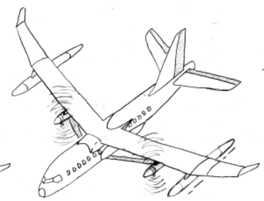
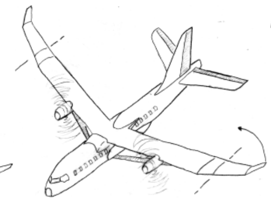
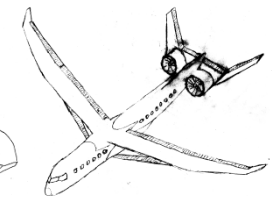
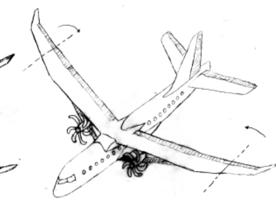
Notional Example

SUGAR's Concept Workshop Process Flow Chart



Consensus Configurations

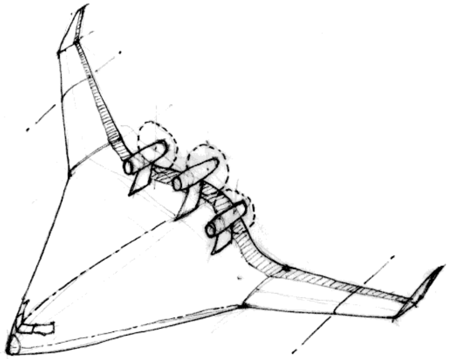
BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

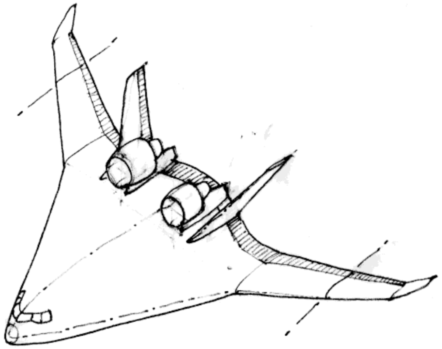
     

	Whole Team Fuel Burn Tube/Wing; #1	Whole Team LTO NOx #1	Whole Team Cruise Emissions #1	Combined Team TOFL #1	Combined Team DNL #1 Tube/Wing	Balanced Vehicle
Number of Fuselages	**1**	**1**	**1**	*1*	*1*	*1*
Wing-Body Blend	*Fairing*	**Fairing**	**Fairing**	*Fairing*	Fairing	Fairing
Passenger Decks	**1**	**1**	**1**	**1**	**1**	**1**
Number	**1**	**1**	**1**	*1*	**1**	**1**
Location	*High*	**High**	**High**	High	High	High
High Lift System	*Conventional*	**Conventional**	**Conventional**	AFC?	AFC	AFC??
Bracing	**Strut**	**Strut**	**Strut**	Strut	*Strut*	*Strut*
Join	**None**	**None**	**None**	*None*	**None**	**None**
Variable Span	**On Ground**	**On Ground**	**On Ground**	*On Ground*	**On Ground**	**On Ground**
Morphing	Variable Camber	Variable Camber	**Variable Camber**	*None*	Variable Camber	Both
Tip Devices	Raked	**Conventional**	Raked	Raked	Raked	Raked
Pitch Effecter	*Conv. Horizontal*	**Conv. Horizontal**	**Conv. Horizontal**	Conv. Horizontal	Something with the "W"	**Conv. Horizontal**
Yaw Effecter	**Conv. Vertical**	**Conv. Vertical**	**Conv. Vertical**	*Conv. Vertical*	H-Tail	*Conv. Vertical*
Roll Effecter	*Aileron / Spoiler*	**Aileron / Spoiler**	**Aileron / Spoiler**	*Aileron/Spoiler*	*Wing Warping*	*Aileron/Spoiler*
Location	**Below Wing**	**Below Wing**	**Below Wing**	Mid Wing	Aft Fuselage	**Below Wing**
Propulsor Type	*Open Rotor - with variable RPM, pitch*	*Open Rotor*	**Open Rotor**	*Open Rotor*	**Ultra High BPR Fan**	*Open Rotor or Ultra High BPR Fan*
Propulsor /core	**Single**	**Single**	**Single**	Single	Single	Single
Energy Conversion	Fuel Cell/Motor	Electric Motor	Electric Motor	Brayton	Fuel Cell/Motor	Fuel Cell/Motor
Augmentation	ed. Brayton	**Fuel Cell**	None	None	None	Battery
Primary Fuel	Liquid Hydrocarbon	Batteries	Batteries	**Liquid Hydrocarbon**	**Liquid Hydrocarbon**	**Liquid Hydrocarbon**

HWB Configurations

		Whole Team Fuel Burn; #2	Combined Team DNL #2 HWB
Fuse	**Number of Fuselages**	**1**	*1*
	Wing-Body Blend	Extreme Blend	Extreme Blend
	Passenger Decks	**1**	**1**
Wing	**Number**	**1**	**1**
	Location	Mid	Mid
	High Lift System	AFC	AFC
	Bracing	**None**	*None*
	Join	**None**	**None**
	Folding	**On Ground**	**On Ground**
	Morphing	None	None
	Tip Devices	Conventional	Raked
S&C	**Pitch Effecter**	Wing TE	Wing TE
	Yaw Effecter	**Winglet**	H-Tail
	Roll Effecter	*Aileron/Spoiler*	Aileron/Spoiler
Propulsor Integration	**Location**	**Aft Fuselage**	*Above Wing*
	Propulsor Type	*Open Rotor - with*	**Ultra High BPR Fan**
	Propulsors per Core	**Single**	Single
	Energy Conversion	Fuel Cell/Motor	Electric motor
	Augmentation	Batteries	None
	Primary Fuel	Hydrogen	**Battery**



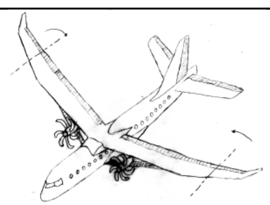


Concepts For Consideration

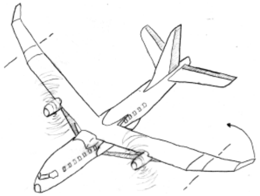
N
Baseline

N+3
Reference

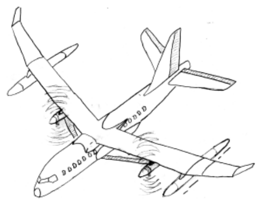
N+3
Improved L/D



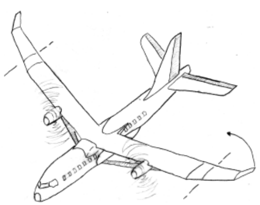
N+3
Fuel-Cell



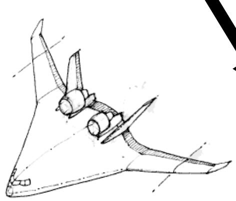
N+3
Emissions (Batteries)



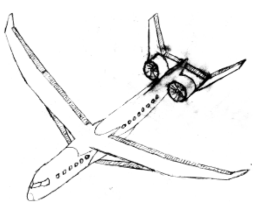
N+3
TOFL



N+3
Reduced Noise HWB



N+3
Reduced Noise



Concept Recommendations

BCA – Advanced Concepts

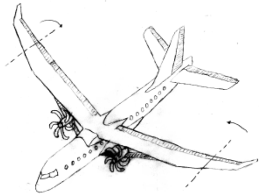
BR&T – Platform Performance Technology

N
Baseline

N+3
Reference

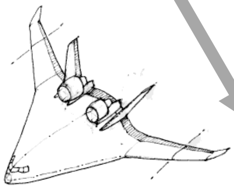
- **Aircraft Size = Medium (only)**
- **TOFL can be looked at as a parametric on one or more of the concepts**

N+3
Improved
L/D



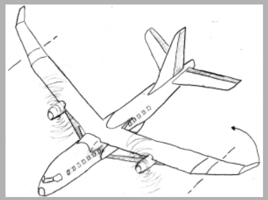
Also, top level look at non-braced wing version for comparison

N+3
Reduced
Noise HWB

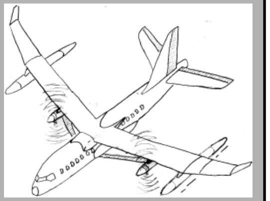


Electric Trade Aircraft*

N+3
Fuel-Cell

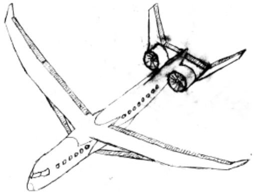


N+3
Emissions
(Batteries)

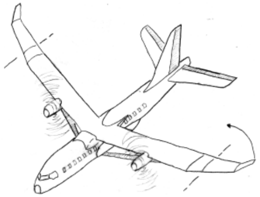


** Includes hybrids with conventional brayton cycle engines*

N+3
Reduced
Noise



N+3
TOFL



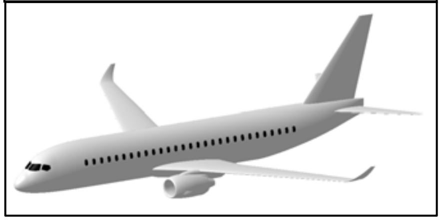
Grey = Selected for Analysis

Concept Selections & Nicknames

BCA – Advanced Concepts

BR&T – Platform Performance Technology

N
Baseline
"SUGAR Free"



765-086-200

N+3
Reference
"Refined SUGAR"

765-094-200

N+3 High L/D
"SUGAR High"

765-095-200

N+3 Electric Trade Aircraft
"SUGAR Volt"

- **Fuel-Cell**
- **Batteries**
- **Hybrid**

765-096-200

N+3
Reduced Noise HWB
"SUGAR Ray"

765-097-200

Structures Technologies Summary

BCA – Advanced Concepts

BR&T – Platform Performance Technology

Structures Technology Areas	Configuration				
	'N' SUGAR Free	**'N+3' Refined SUGAR**	**'N+3' SUGAR High**	**'N+3' SUGAR Volt**	**'N+3' SUGAR Ray**
Materials / Manufacturing	Aluminum	Adv. Composites incl. Hybrid Polymer, Adv. Metals, Adv. Joining, Adv. Ceramics			
Health Management	None On-Board	On-board Structurally Integrated SHM, Advanced NDE/NDI			
Loads & Environments	None	Maximize Flight Control Integration, Active/Passive Aeroelastic Response for Load Control			
Design & Criteria	Deterministic	Reliability Based, Robust/Unitized, Multi-Functional Structures, Support for NLF			
Adaptive Structures for Control Systems	Conventional	Conformal, Gapless, Adaptive, Spanwise Load Control			
Energy Management	No Structural Integration	Structurally Integrated Thermal and Electrical Energy Management			
Coatings	Conventional Paint and Corrosion Prev.	Enable Lightweight Materials, Energy Harvesting, Thermal Management, Drag Reduction			
Interiors	Standard	More Lightweight			
Additional Structures Technologies	None	Environmentally Compliant Manufacturing, Struct. Integrated Systems (Wiring)	Lightweight Wing Folds, Adv. Lightweight High Lift Systems, Adv. Material Forms		Lightweight Wing Folds, Adv. Material Forms, Adv. Non-Circular Fuse.

Subsystems Technologies Summary

BCA – Advanced Concepts

BR&T – Platform Performance Technology

Subsystem Technology Areas	Configuration: 'N' SUGAR Free	Configuration: 'N+3' Refined SUGAR	Configuration: 'N+3' SUGAR High	Configuration: 'N+3' SUGAR Volt	Configuration: 'N+3' SUGAR Ray
Power Management	Conventional	Adaptive			
Power Generation	Eng. Primary; APU Gnd. & Bkup.				
APU	Conventional	Conventional or Diesel			
Actuators	Hydraulic	Hydraulic & EMA	EMA		
Control Architecture	Cable / Pulley	Maximize Use of Fiberoptics			
Thermal Technology	Conventional	Lightweight			
Electro Magnetic Effects / Lightning	Conventional	More Tolerant Systems & Dual Use Structure			
Fuel	Jet-A	Low Sulfur Jet-A & Drop in Synthetic or Biofuels			
Flight Avionics	Conventional	NextGen ATM Capable			
Wiring	Copper	Copper w/ Current Return Networks	High Conductivity, Lightweight		
Computing Networks	None	Integrated			

Aero Technologies Summary

BCA – Advanced Concepts

BR&T – Platform Performance Technology

Aero Technology Areas	Configuration				
	‘N’ SUGAR Free	**‘N+3’ Refined SUGAR**	**‘N+3’ SUGAR High**	**‘N+3’ SUGAR Volt**	**‘N+3’ SUGAR Ray**
Laminar Flow	None	Passive/Natural and Active Where Appropriate			
Riblets	None	Fuselage	Fuselage and Wing Where Appropriate		
Excrescence Drag	Conventional	Multi-Functional Structures, Reduced Fasteners, Reduced Flap Fairings			
Empennage	Conventional Size	Relaxed Static Stability & Increased C_{LMax} for reduced Size			
Airfoil Technology	Supercritical		Advanced Supercritical		Supercritical
Additional Technologies	None		Low Interference Nacelles Low Drag Strut Integration		Low Interference Nacelles Airframe Noise Shielding

Propulsion Technologies Summary

BCA – Advanced Concepts

BR&T – Platform Performance Technology

Propulsion Technology Areas	Configuration				
	'N' SUGAR Free	'N+3' Refined SUGAR	'N+3' SUGAR High	'N+3' SUGAR Volt	'N+3' SUGAR Ray
Engine Cycle	CFM56	Very high BPR turbofan with 2030 engine technologies	Very high BPR turbofan with Advanced engine technologies	, Fuel Cell/Gas Turbine Hybrid (SUGAR High Tech Level)	SUGAR High
Combustor	Conventional	Advanced low-emissions combustor	Variable Flow Splits, Ultra-compact low emissions combustor	SUGAR High + on fuel cell reformer	SUGAR High
Materials	Conventional	Adv. PMCs, TiAl, Adv disk material/process, Adv shaft mat'l, CMC blades/vanes	Refined SUGAR Mat'ls + MMC's, Advanced CMC mat'ls & processes	SiC MOSFET, motor controller, lightweight magnetics & ferrites, CMC's	SUGAR High
Acoustic	Conventional	Adv. inlet/nozzle treatment, Adv. liner mat'ls, Adv. Chevrons, Blade & OGV optimization	Refined SUGAR Techs. + Active noise control/fluidics, Non-Ax symmetric nozzles, Unique/shielded installations, others (as needed)		
Mechanical	Conventional	High DN Bearings, Adv. High Temp Seals	Additional advanced systems (as needed)		

Point of Departure Study – Objectives

Objectives:

- **Provide starting points for more detailed analysis that will follow**
  - Provide initial assumptions for engine and aircraft size and weight
- **Provide initial assessment of where we are relative to NASA N+3 fuel burn goals**
- **Investigate trade space for electric aircraft**
  - Parametrically vary battery and fuel cell technology levels
  - Evaluate use of hybrid systems

Please note: We continued to refine the numbers as configurations were analyzed and sized and as the technology groups quantified their technology impacts

Point of Departure Analysis - Initial Performance

BCA – Advanced Concepts | BR&T – Platform Performance Technology

N
Baseline
"SUGAR Free"

Fuel Burn Baseline

N+3
Reference
"Refined SUGAR"

-50% Fuel Burn

N+3 High L/D
"SUGAR High"

-58% Fuel Burn

N+3 Electric Trade Aircraft
"SUGAR Volt"

- Fuel-Cell
- Batteries
- Hybrid

Up to -88%
Fuel Burn

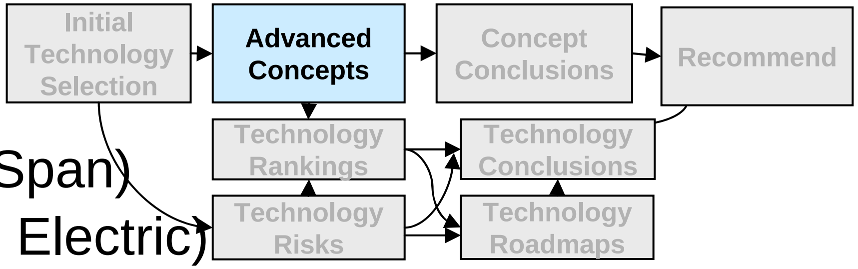
N+3
Reduced Noise HWB
"SUGAR Ray"

Not analyzed

SUGAR Phase 1 Final Review

8:45

- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- **Concept Performance and Sizing from 12-Month Review**
  - SUGAR Free (N Baseline)
  - Refined SUGAR (N+3 Reference)
  - SUGAR High (N+3 Advanced High Span)
  - SUGAR Volt (N+3 Advanced Hybrid Electric)
  - SUGAR Ray (N+3 Advanced HWB Low Noise)
  - Sized Vehicle Summary & Comparisons



- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- Lunch
- Proprietary Session

SUGAR Phase 1 Final Review

BCA – Advanced Concepts | BR&T – Platform Performance Technology

8:45

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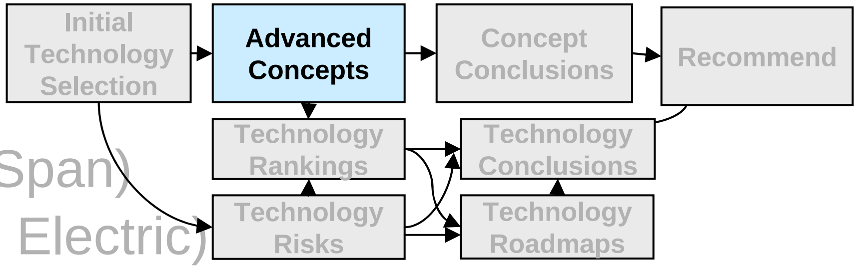
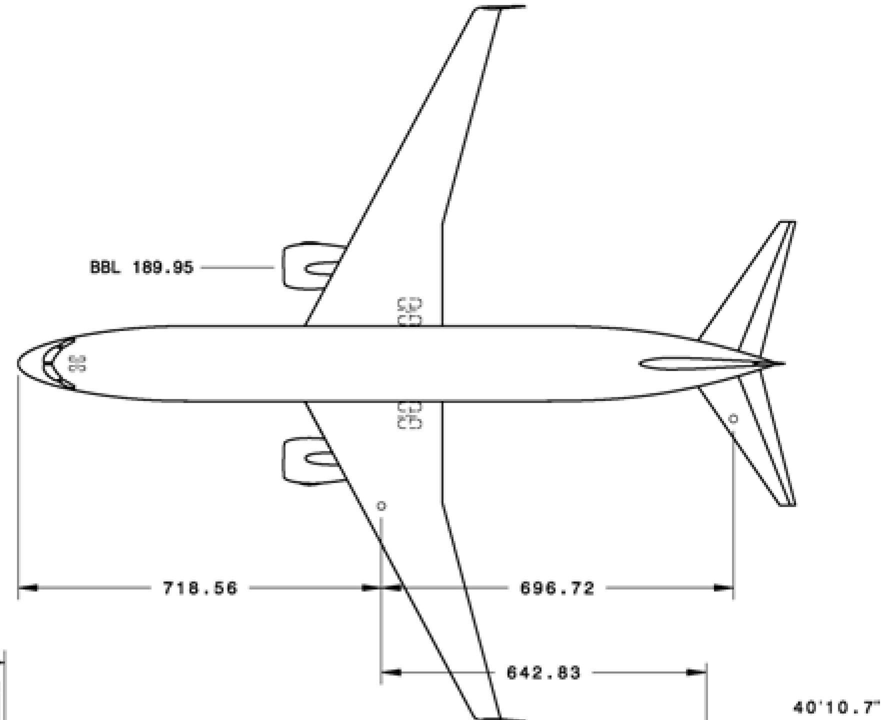
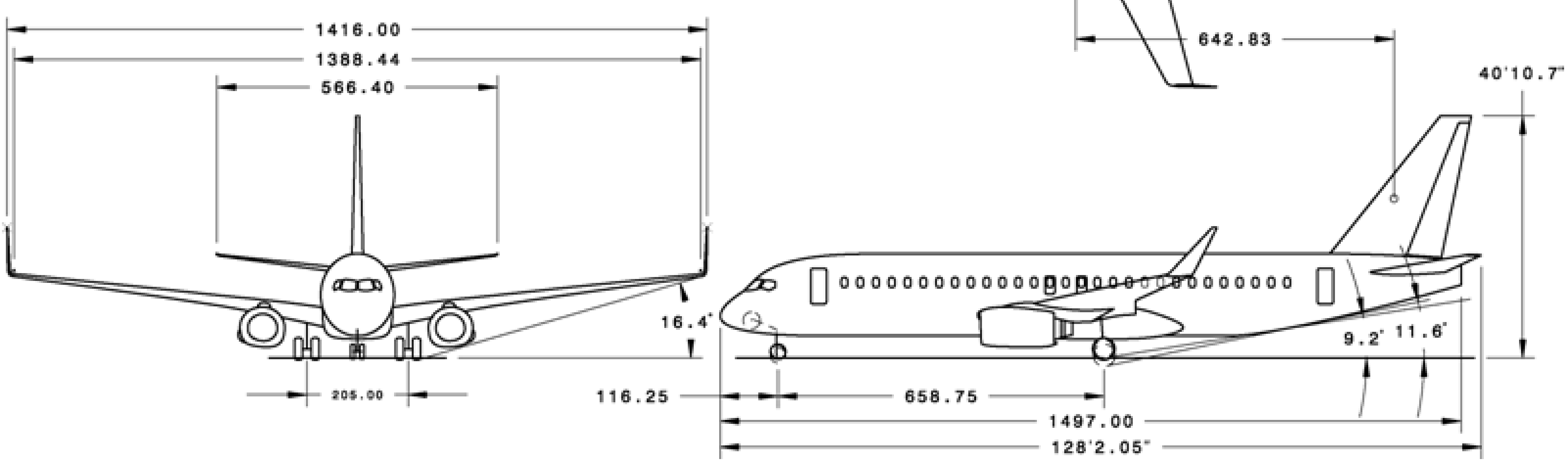


Sugar Free (765-093) – Three View

	WING W/TIP Wimpress	V-TAIL Trap	H-TAIL Trap
Area*	1532.20**	284.58	357.14
Aspect Ratio*	9.760**	1.940	6.237
Taper Ratio	0.137**	0.271	0.202
MAC Inches	163.00**	161.24	104.10
Dihedral (Deg.)	6.0	-	6.0
1/4 Chord Sweep (Deg.)*	25.14	33.20	30.00
Root Chord (Inches)	312.30	228.64	151.00
Tip Chord (Inches)	42.90	62.00	30.60
Span (W/O Winglet)*	1388.44	282.00	566.40
Volume Coeffec.	-	???	???

* Projected
** W/O Winglet





SUGAR Free – Technology Description

BCA – Advanced Concepts

Subsystem Technologies	
Power Management	Conventional
Power Generation	Eng. Primary; APU Gnd. & Bkup.
APU	Conventional
Actuators	Hydraulic
Control Architecture	Cable / Pulley
Thermal Technology	Conventional
Electro Magnetic Effects / Lightning	Conventional
Fuel	Jet-A
Flight Avionics	Conventional
Wiring	Copper
Computing Networks	None

Aero Technologies	
Laminar Flow	None
Riblets	None
Excrescence Drag	Conventional
Empennage	Conventional Size
Airfoil Technology	Supercritical
Additional Technologies	None

BR&T – Platform Performance Technology

Structural Technologies	
Materials / Manufacturing	Aluminum
Health Management	None On-Board
Loads & Environments	None
Design & Criteria	Deterministic
Adaptive Structures for Control Systems	Conventional
Energy Management	No Structural Integration
Coatings	Conventional Paint and Corrosion Prev.
Interiors	Standard
Additional Structures Technologies	None

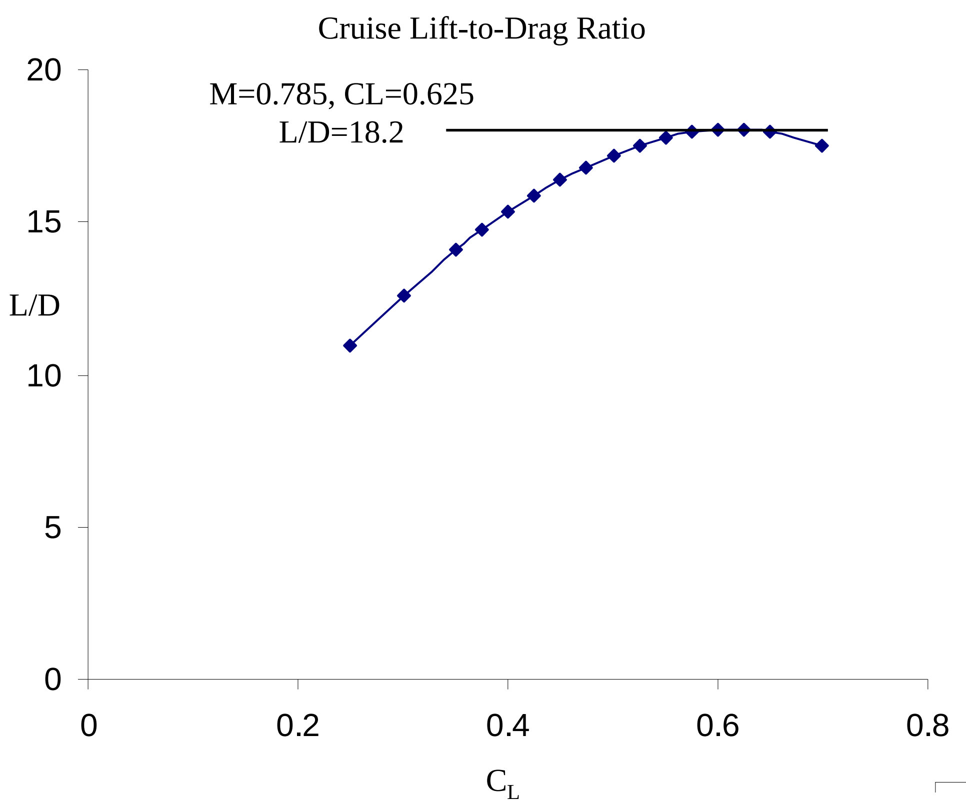
Propulsion Technologies	
Engine Cycle	CFM56
Combustor	Conventional
Materials	Conventional
Acoustic	Conventional
Mechanical	Conventional

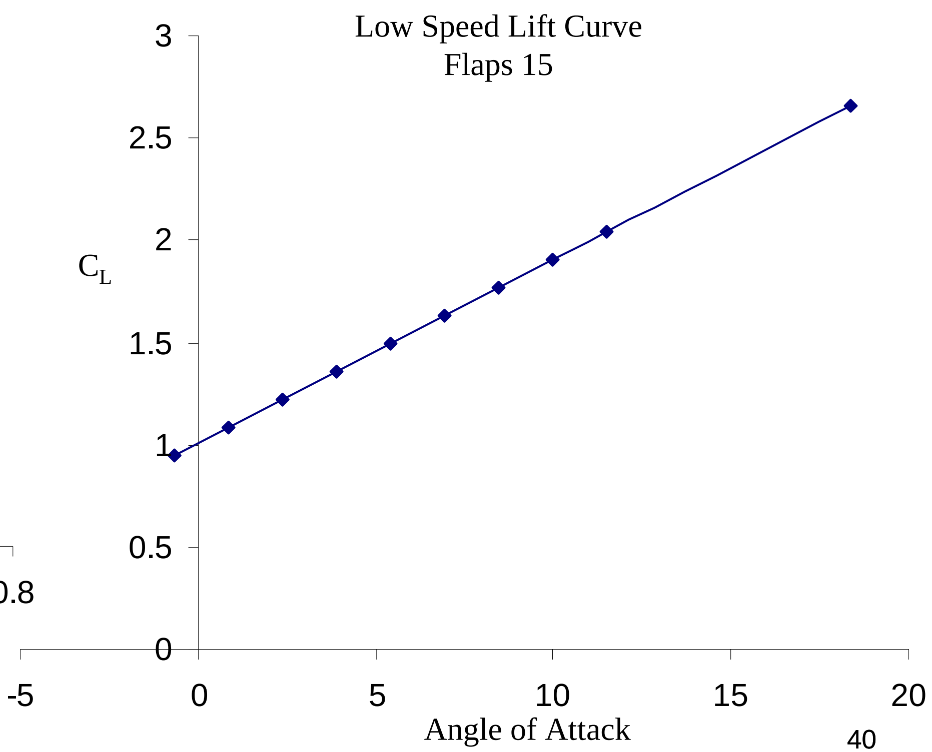
SUGAR Free - Aero

BCA – Advanced Concepts

BR&T – Platform Performance Technology

Reference Baseline

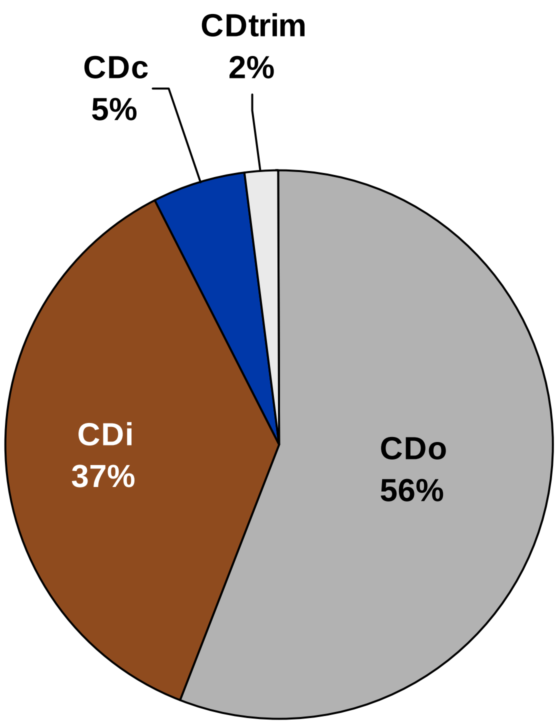




SUGAR Free – Aerodynamics Baseline
High Speed Build-Up

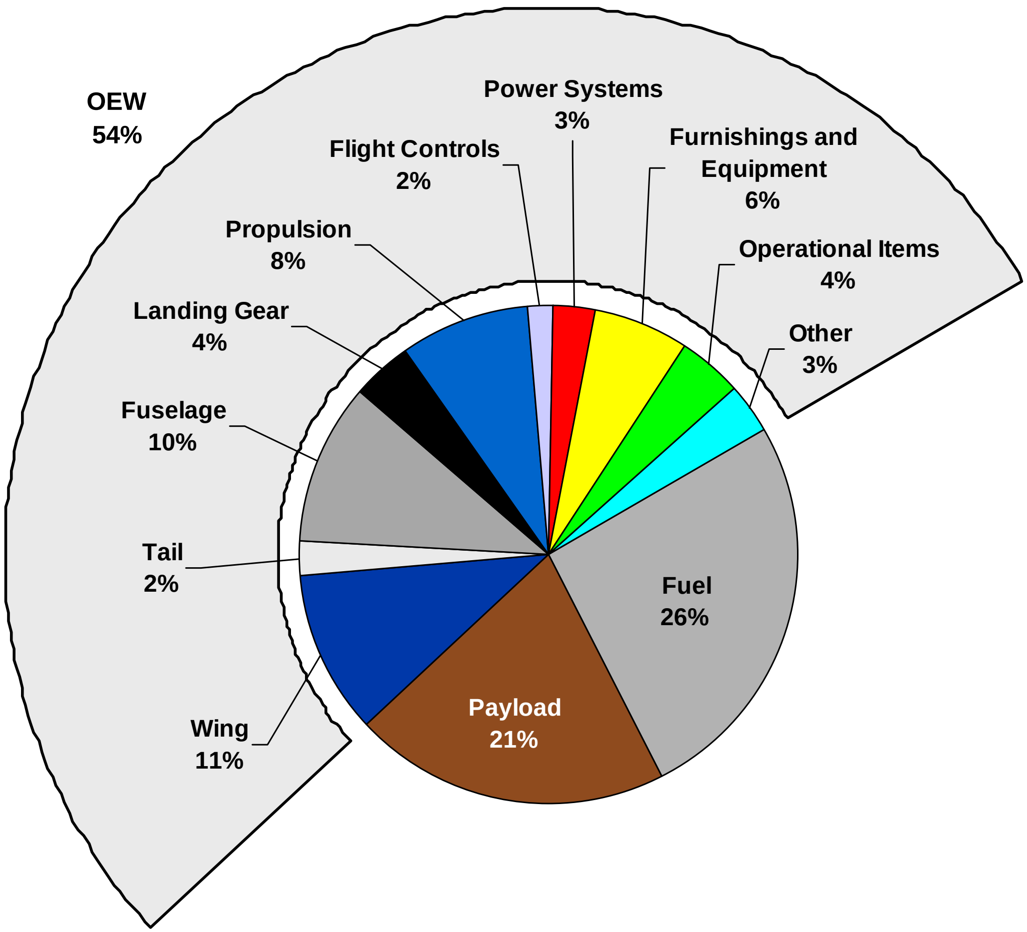
BCA – Advanced Concepts | BR&T – Platform Performance Technology

SUGAR Free	
SREF (FT**2)	1429
FN (LBS)	28168
AR	10.41
SWEEP (DEG)	25
T/C-AVE	0.1258
AIRFOIL TYPE	SUPERCRITICAL
S-HORIZ (FT**2)	353.903
S-VERT (FT**2)	289.502
F BUILD-UP (FT2)**	
FUSELAGE	8.8533
WING	8.6164
WINGLET	0.2105
HORIZONTAL	1.9395
VERTICAL	1.6832
N&P	2.9600
CANOPY	0.0405
GEAR PODS	0.0000
ETC BEFORE SUB	0.0400
EXCRESCENCE	2.2883
UPSWEEP	0.5076
WING TWIST	0.3415
STRAKES	0.0000
ETC AFTER SUB	-0.6000
FUSELAGE BUMP	0.5000
F-TOTAL (FT2)**	**27.3808**
E-VISC	**0.944**
CRUISE CD BUILD-UP	
M-CRUISE	0.78
CL-CRUISE	0.625
CRUISE ALTITUDE	35000
CD0	0.01916
CDI	0.01265
CDC	0.00186
CDTRIM	0.00069
CDTOT	**0.03436**
L/D	**18.189**



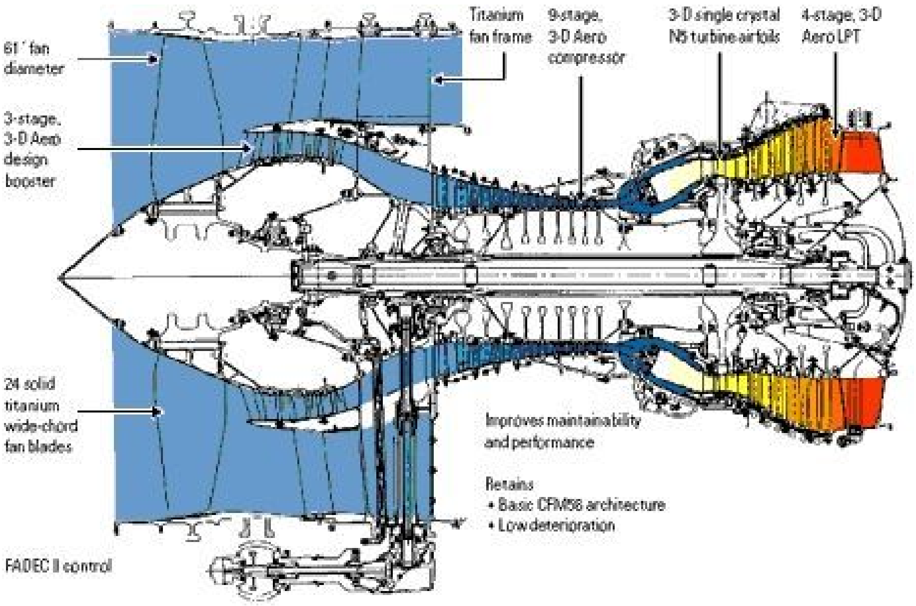
SUGAR Free - Mass Properties

GROUP	WEIGHT (LB)	
WING	**18,728**	
BENDING MATERIAL		9,621
SPAR WEBS		1,290
RIBS AND BULKHEADS		1,226
AERODYNAMIC SURFACES		3,351
SECONDARY STRUCTURE		3,240
TAIL	**3,779**	
FUSELAGE	**18,392**	
LANDING GEAR	**6,712**	
PYLON	**1,858**	
PROPULSION	**14,874**	
ENGINES		10,404
ENGINE SYSTEMS		263
EXHAUST SYSTEM		3,688
FUEL SYSTEM		520
FLIGHT CONTROLS	**3,084**	
COCKPIT CONTROLS		252
SYSTEM CONTROLS		2,832
POWER SYSTEMS	**4,483**	
AUXILIARY POWER PLANT		1,032
HYDRAULICS		894
ELECTRICAL		2,557
INSTRUMENTS	**686**	
AVIONICS & AUTOPILOT	**1,533**	
FURNISHINGS & EQUIPMENT	**10,866**	
AIR CONDITIONING	**1,678**	
ANTI-ICING	**118**	
MANUFACTURER'S EMPTY WEIGHT (MEW)	**86,790**	
OPERATIONAL ITEMS	7,342	
OPERATING EMPTY WEIGHT (OEW)	**94,132**	
USABLE FUEL	45,313	
PAYLOAD	36,190	
TAKEOFF GROSS WEIGHT (TOGW)	**175,635**	



SUGAR Free – Propulsion

- **The baseline engine is a CFM56-7B**



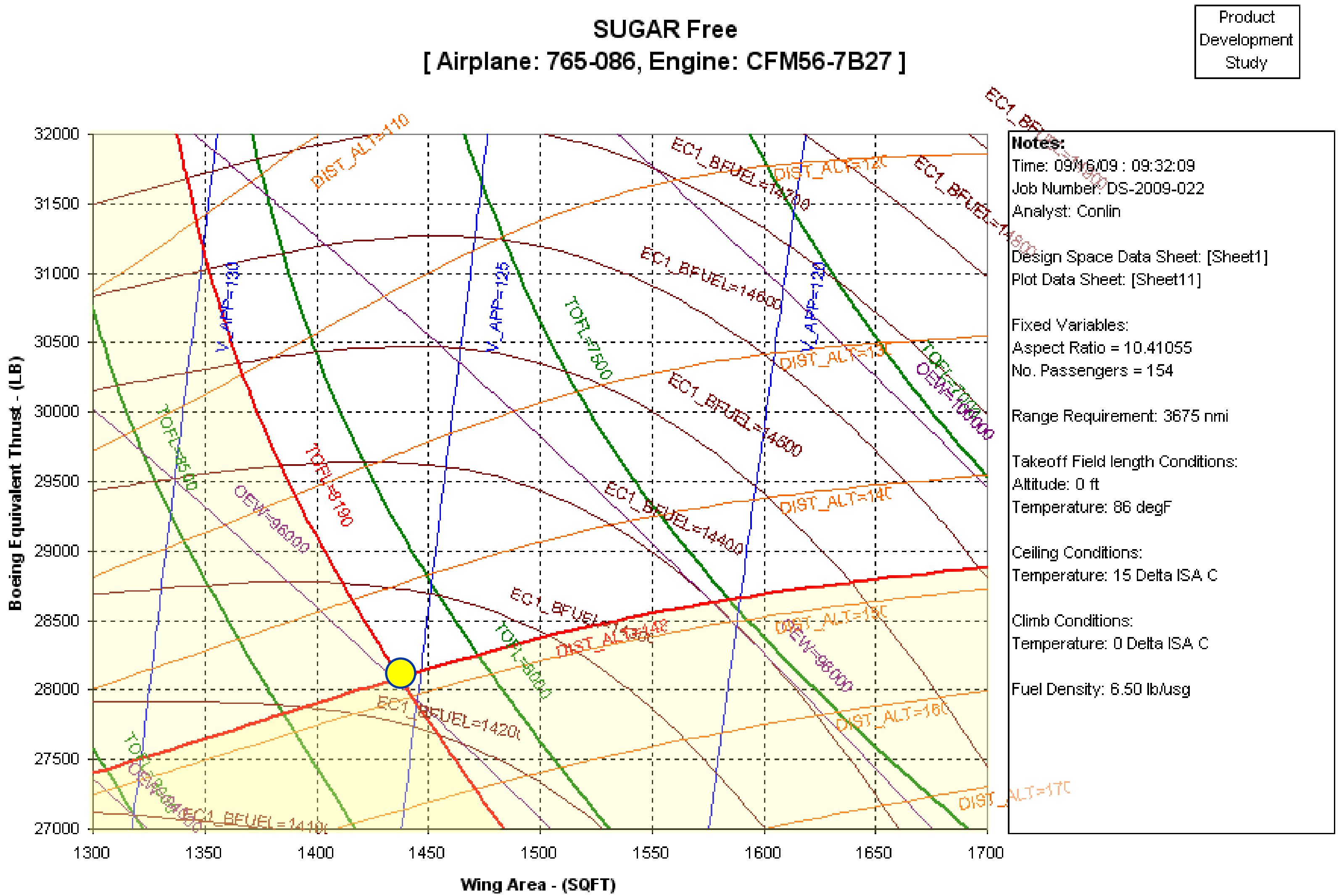
Basic dry weight	5216	lbm
Fan diameter	61	in
Length	98.7	in
Performance	**Thrust, lbf**	**SFC, lbm/lbf-hr**
SLS	27300	- - -
Rolling takeoff	- - -	- - -
Top-of-climb	5962	- - -
Cruise	5480	- - -
Emissions	-30%	relative to CAEP/6

Projected Technologies
Current CFM56-7B bill of materials

SUGAR Free - Sizing

BCA – Advanced Concepts

BR&T – Platform Performance Technology



SUGAR Free – Performance

PERFORMANCE SUMMARY
SUGAR Free

Product Development Study

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		SUGAR Free
PASSENGERS / CLASS		154 / Dual
MAX TAKEOFF WEIGHT	LB	184,800
MAX LANDING WEIGHT	LB	151,000
MAX ZERO FUEL WEIGHT	LB	142,000
OPERATING EMPTY WEIGHT	LB	96,000
FUEL CAPACITY REQ	USG	9,710
ENGINE MODEL		Scaled CFM56-7B27
FAN DIAMETER	IN	62
BOEING EQUIVLENT THRUST (BET)	LB	28,200
WING AREA / SPAN	FT^2 / FT	1429 / 122
ASPECT RATIO (EFFECTIVE)		10.41
OPTIMUM CL		0.583
CRUISE L/D @ OPT CL		18.068
DESIGN MISSION RANGE	NMI	3,500
PERFORMANCE CRUISE MACH		0.785
LONG RANGE CRUISE MACH (LRC)		0.785
THRUST ICAC (MTOW, ISA)	FT	37,200
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	23 / 148
OPTIMUM ALTITUDE (MTOW, ISA)	FT	35,000
BUFFET ICAC (MTOW, ISA)	FT	36,200
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190
APPROACH SPEED (MLW)	KT	126
BLOCK FUEL / SEAT (900 NMI)	LB	92.35

Baseline for Study

SUGAR Free – Mission Trade

BCA – Advanced Concepts

BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR Free – Future ATM Trade

Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		**N Reference Mission**	**N+3 Reference Mission**
PASSENGERS / CLASS		154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	184,800	173,300
MAX LANDING WEIGHT	LB	151,000	147,500
MAX ZERO FUEL WEIGHT	LB	142,000	138,500
OPERATING EMPTY WEIGHT	LB	96,000	92,500
FUEL CAPACITY REQ	USG	9,710	8,414
ENGINE MODEL		Scaled CFM56-7B27	Scaled CFM56-7B27
FAN DIAMETER	IN	62	61
BOEING EQUIVLENT THRUST (BET)	LB	28,200	26,800
WING AREA / SPAN	FT^2 / FT	1429 / 122	1314 / 117
ASPECT RATIO (EFFECTIVE)		10.41	10.41
OPTIMUM CL		0.583	0.589
CRUISE L/D @ OPT CL		18.068	17.695
DESIGN MISSION RANGE	NMI	3,500	3,500
PERFORMANCE CRUISE MACH		0.785	0.785
LONG RANGE CRUISE MACH (LRC)		0.785	0.785
THRUST ICAC (MTOW, ISA)	FT	37,200	37,100
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	23 / 148	22 / 148
OPTIMUM ALTITUDE (MTOW, ISA)	FT	35,000	34,700
BUFFET ICAC (MTOW, ISA)	FT	36,200	35,700
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190	8,190
APPROACH SPEED (MLW)	KT	126	130
BLOCK FUEL / SEAT (900 NMI)	LB	92.35 (Base)	76.14 (-17.5%)

NextGen N+3 mission rules result in 17.5% reduction in fuel burn (assumes aircraft resizing)

* All SUGAR Free data from this point forward is for conventional ATM

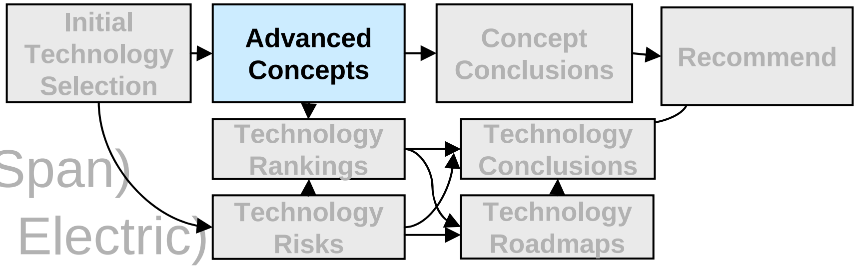
SUGAR Free - Emissions

- **NOX: CAEP/6 TI 79.2%**
- **CO_2: 291 klbs at 900 nmi**
- **CO_2 with Biofuel: 146 klbs at 900 nmi**

SUGAR Phase 1 Final Review

9:00

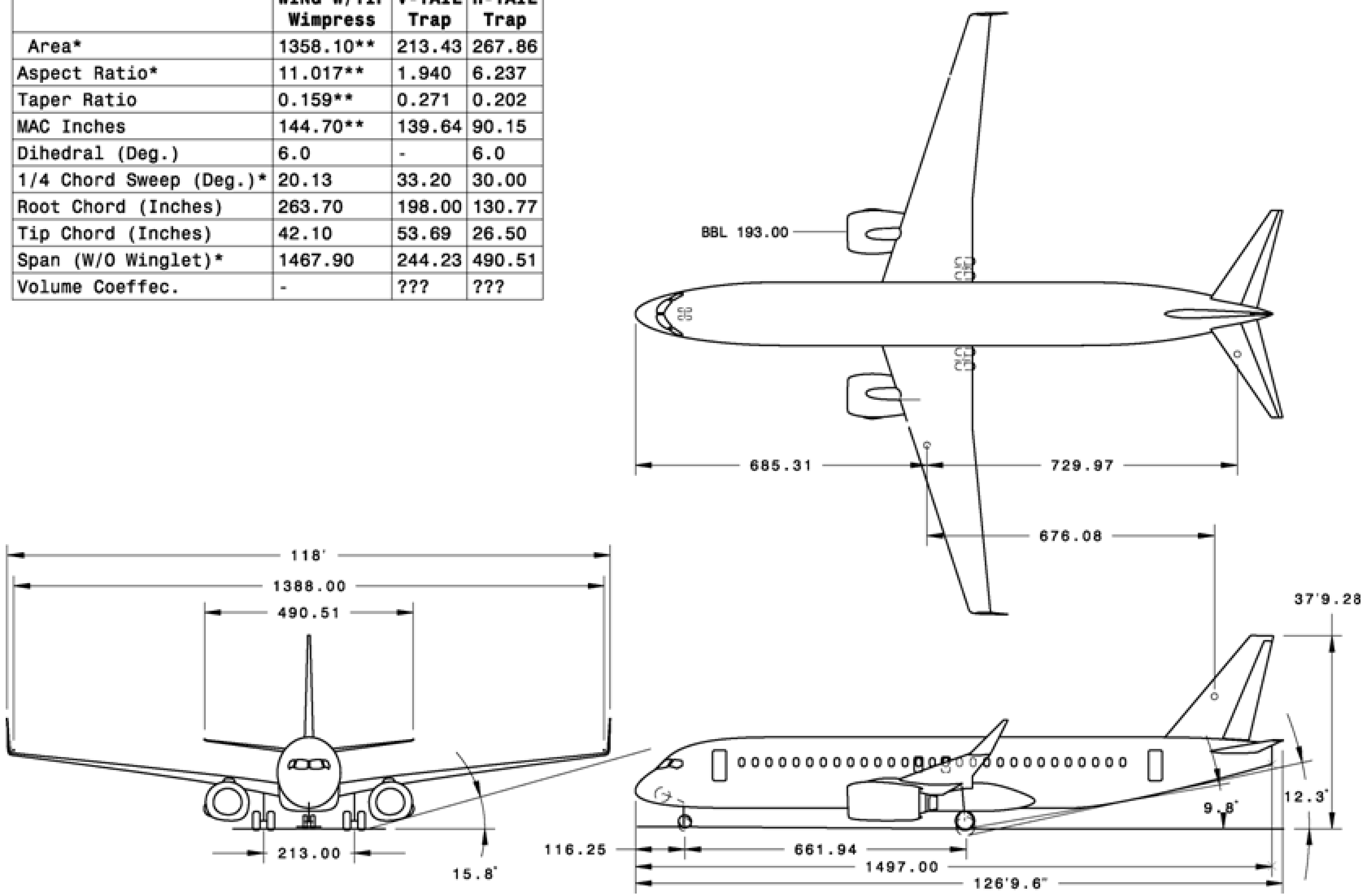
- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- **Concept Performance and Sizing from 12-Month Review**
  - SUGAR Free (N Baseline)
  - Refined SUGAR (N+3 Reference)
  - SUGAR High (N+3 Advanced High Span)
  - SUGAR Volt (N+3 Advanced Hybrid Electric)
  - SUGAR Ray (N+3 Advanced HWB Low Noise)
  - Sized Vehicle Summary & Comparisons



- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- Lunch
- Proprietary Session

Refined SUGAR (765-094) – Three View

	WING W/TIP Wimpress	V-TAIL Trap	H-TAIL Trap
Area*	1358.10**	213.43	267.86
Aspect Ratio*	11.017**	1.940	6.237
Taper Ratio	0.159**	0.271	0.202
MAC Inches	144.70**	139.64	90.15
Dihedral (Deg.)	6.0	-	6.0
1/4 Chord Sweep (Deg.)*	20.13	33.20	30.00
Root Chord (Inches)	263.70	198.00	130.77
Tip Chord (Inches)	42.10	53.69	26.50
Span (W/O Winglet)*	1467.90	244.23	490.51
Volume Coeffec.	-	???	???



Refined SUGAR – Technology Description

BCA – Advanced Concepts

Subsystem Technologies	
Power Management	Adaptive
Power Generation	Eng. Primary; APU Gnd. & Bkup.
APU	Conventional or Diesel
Actuators	Hydraulic & EMA
Control Architecture	Maximize Use of Fiberoptics
Thermal Technology	Lightweight
Electro Magnetic Effects / Lightning	More Tolerant Systems & Dual Use Structure
Fuel	Low Sulfur Jet-A, Synthetic or Biofuels
Flight Avionics	NextGen ATM Capable
Wiring	Copper w/ Current Return Networks
Computing Networks	Integrated

Aero Technologies	
Laminar Flow	Passive/Natural and Active Where Appropriate
Riblets	Fuselage
Excrescence Drag	Multi-Functional Structures, Reduced Fasteners, Reduced Flap Fairings
Empennage	Relaxed Static Stability & Increased C_{LMax}
Airfoil Technology	Supercritical
Additional Technologies	None

BR&T – Platform Performance Technology

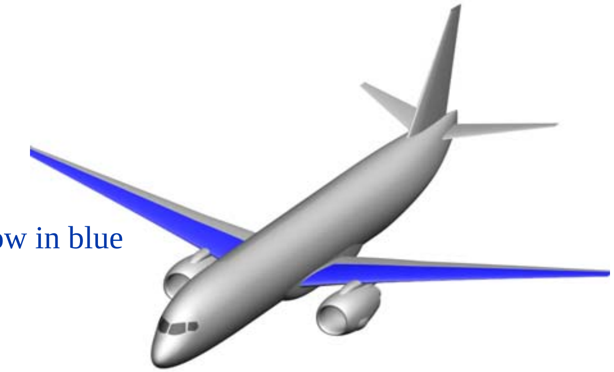
Structural Technologies	
Materials / Manufacturing	Adv. Composites incl. Hybrid Polymer, Adv. Metals, Adv. Joining, Adv. Ceramics
Health Management	On-board Structurally Integrated SHM, Advanced NDE/NDI
Loads & Environments	Maximize Flight Control Integration, Active/Passive Aeroelastic Response for Load Control
Design & Criteria	Reliability Based, Robust/Unitized, Multi-Functional Structures, Support for NLF
Adaptive Structures for Control Systems	Conformal, Gapless, Adaptive, Spanwise Load Control
Energy Management	Structurally Integrated Thermal and Electrical Energy Management
Coatings	Enable Lightweight Materials, Energy Harvesting, Thermal Management, Drag Reduction
Interiors	More Lightweight
Additional Structures Technologies	Environmentally Compliant Manufacturing, Struct. Integrated Systems (Wiring)

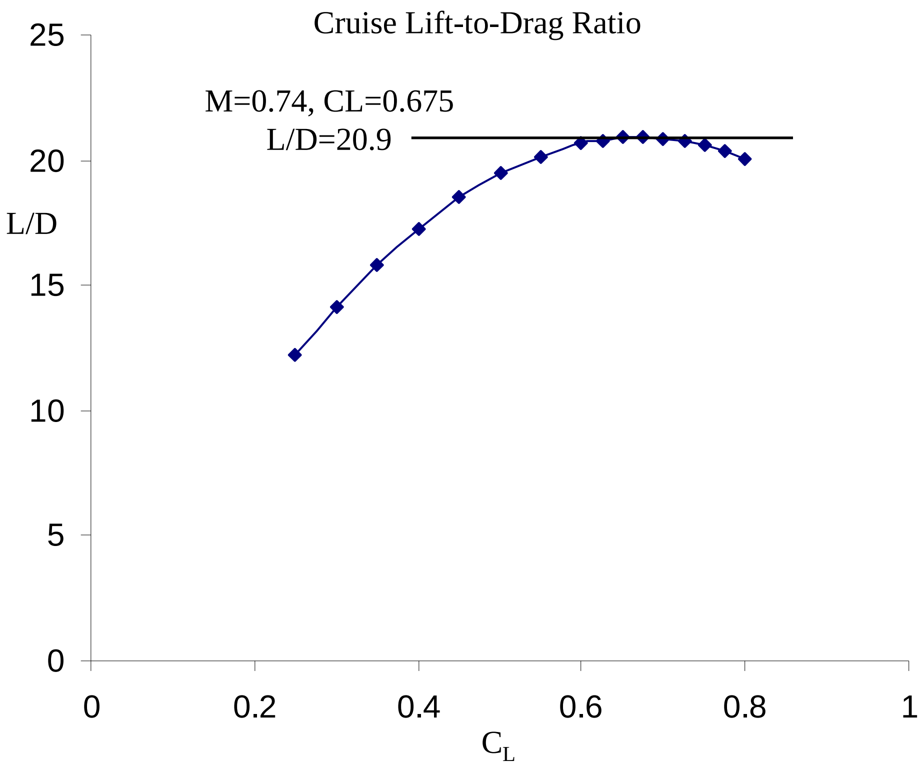
Propulsion Technologies	
Engine Cycle	Very high BPR turbofan with 2030 engine technologies
Combustor	Advanced low-emissions combustor
Materials	Adv. PMCs, TiAl, Adv disk material/process, Adv shaft mat'l,
Acoustic	CMC blades/vanes
Mechanical	High DN Bearings, Adv. High Temp Seals

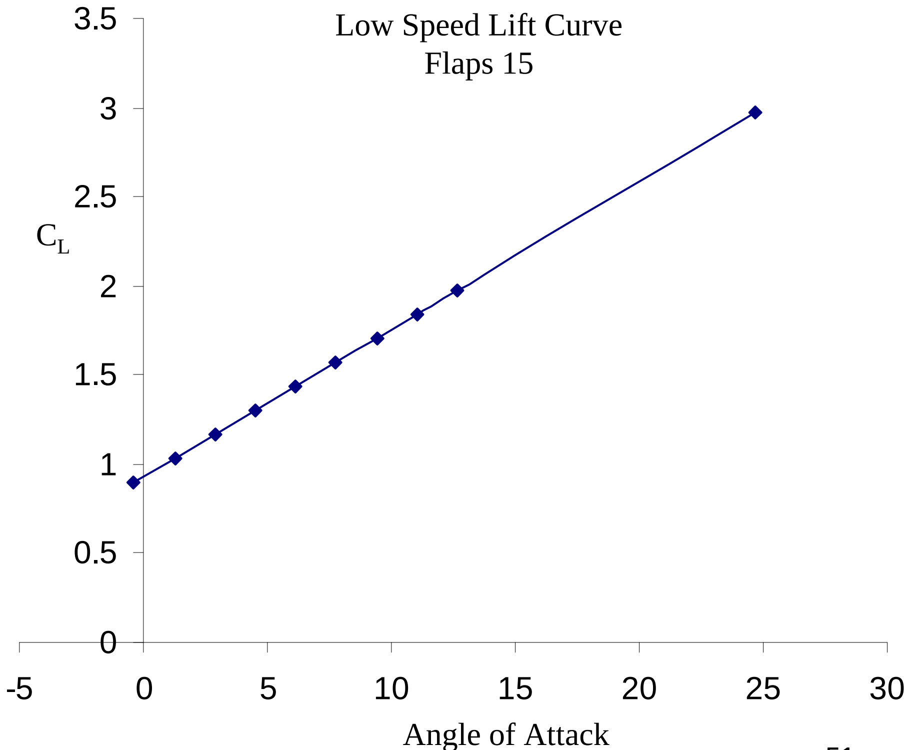
Refined SUGAR - Aero

- Laminar flow over wing
- Riblets on fuselage

Laminar flow in blue

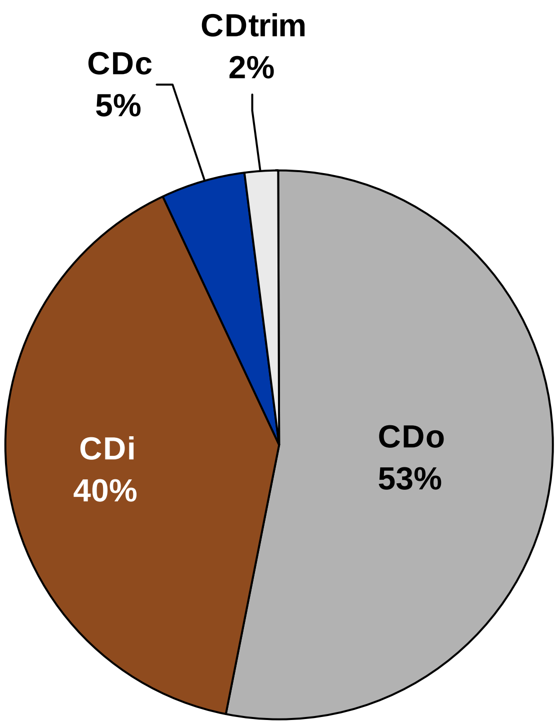






Refined SUGAR – High Speed Aerodynamics

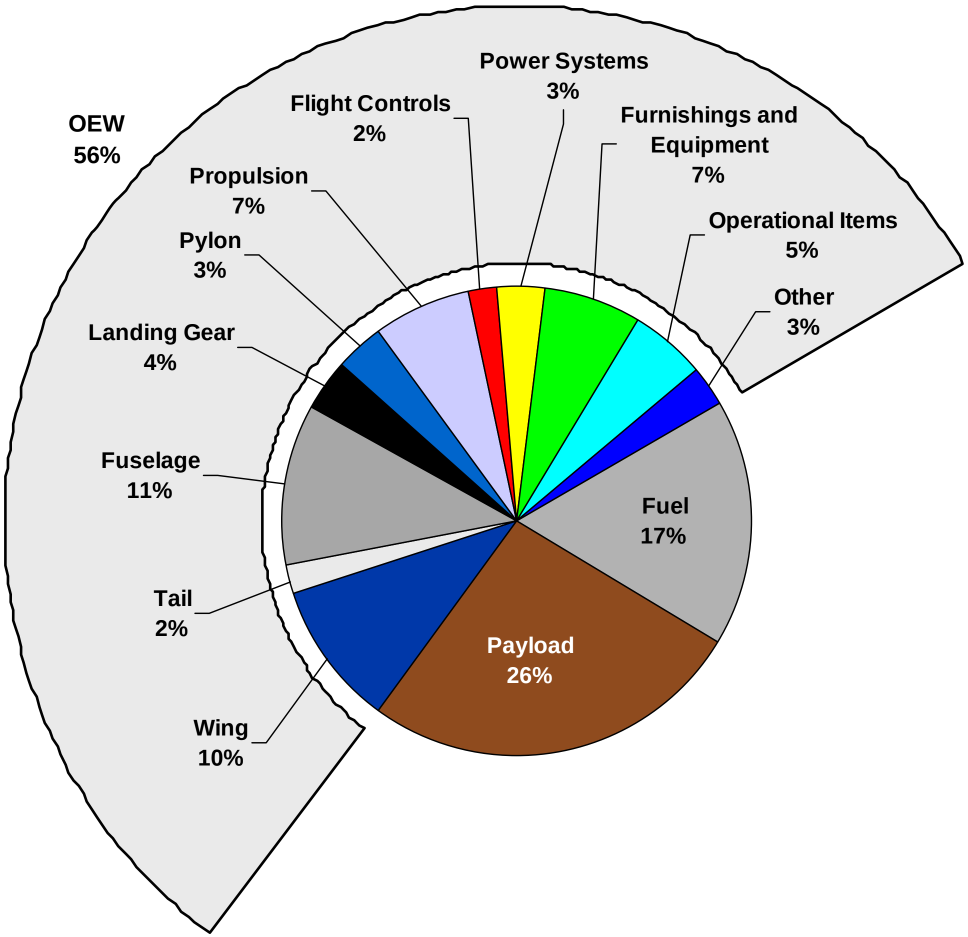
Refined SUGAR	
SREF (FT**2)	1285.92
FN (LBS)	18900
AR	11.636
SWEEP (DEG)	15.08
T/C-AVE	0.1248
AIRFOIL TYPE	SUPERCRITICAL
S-HORIZ (FT**2)	265.868
S-VERT (FT**2)	213.444
F BUILD-UP (FT2)**	
FUSELAGE	9.2989
WING	8.1036
WINGLET	0.2173
HORIZONTAL	1.4215
VERTICAL	1.2158
N&P	2.8600
CANOPY	0.0405
GEAR PODS	0.0000
ETC BEFORE SUB	-3.5400
EXCRESCENCE	1.5239
UPSWEEP	0.6012
WING TWIST	0.3948
STRAKES	0.0000
ETC AFTER SUB	-0.6500
FUSELAGE BUMP	0.5430
F-TOTAL (FT2)**	**22.0305**
E-VISC	**0.966**
CRUISE CD BUILD-UP	
M-CRUISE	0.74
CL-CRUISE	0.675
CRUISE ALTITUDE	38408
CD0	0.01713
CDI	0.01290
CDC	0.00159
CDTRIM	0.00065
CDTOT	**0.03227**
L/D	**20.915**



Refined SUGAR - Mass Properties

BCA – Advanced Concepts BR&T – Platform Performance Technology

GROUP	WEIGHT (LB)	
WING	**13,695**	
BENDING MATERIAL		5,881
SPAR WEBS		1,016
RIBS AND BULKHEADS		1,036
AERODYNAMIC SURFACES		2,850
SECONDARY STRUCTURE		2,911
TAIL	**2,671**	
FUSELAGE	**14,991**	
LANDING GEAR	**5,052**	
NACELLE & PYLON (Strut)	**4,412**	
PROPULSION	**9,027**	
ENGINES		8,410
FUEL SYSTEM `		617
FLIGHT CONTROLS	**2,900**	
COCKPIT CONTROLS		252
SYSTEM CONTROLS		2,648
POWER SYSTEMS	**4,146**	
AUXILIARY POWER PLANT		1,014
HYDRAULICS		836
ELECTRICAL		2,297
INSTRUMENTS	**773**	
AVIONICS & AUTOPILOT	**1,504**	
FURNISHINGS & EQUIPMENT	**9,115**	
AIR CONDITIONING	**1,441**	
ANTI-ICING	**108**	
MANUFACTURER'S EMPTY WEIGHT (MEW)	**69,835**	
OPERATIONAL ITEMS	7,207	
OPERATIONAL EMPTY WEIGHT (OEW)	**77,042**	
USABLE FUEL	23,180	
PAYLOAD	36,190	
TAKEOFF GROSS WEIGHT (TOGW)	**136,412**	



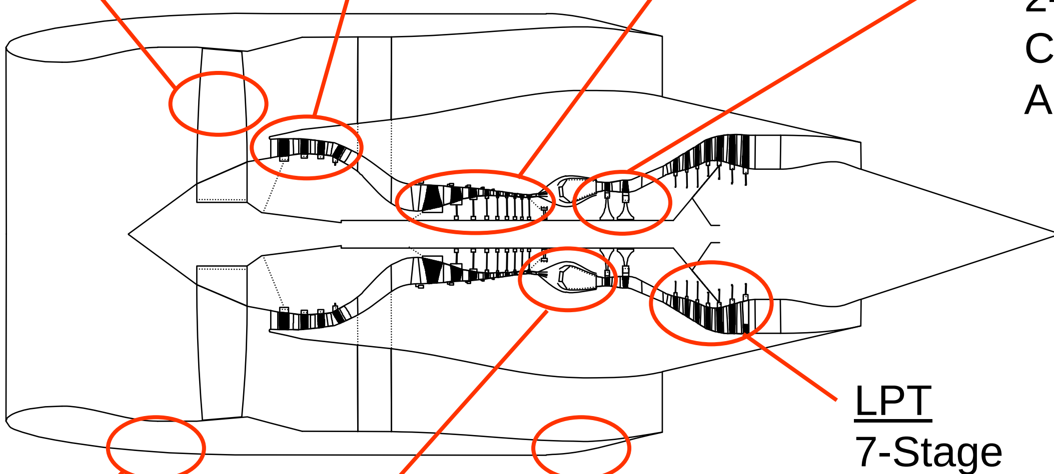
N+3 Reference Engine Architecture (gFan)

Advanced Composite Fan
1.4 PR, 70" fan
Advanced 3-D aero design
Sculpted features, low noise

4-Stage Booster

Ultra-high PR core compressor
66 OPR, 9 BPR
9 stages

HPT
2-Stage
CMC nozzles + blades
Advanced aero Features



LPT
7-Stage
Moderate loading
CMC & TiAl nozzles + blades

Advanced combustor

Advanced nacelle
Highly Integrated
Minimum OD
Unitized composite

Integrated thrust reverser/VFN
Variable fan nozzle

N+3 Reference Engine Description (gFan)

"gFan" Architectural concept

- Boosted 2-spool SFTF, 66 OPR, 9.2 BPR
- Modest hot section temperatures, extensive use of CMCs
- Compatible with emissions goals/advanced combustor

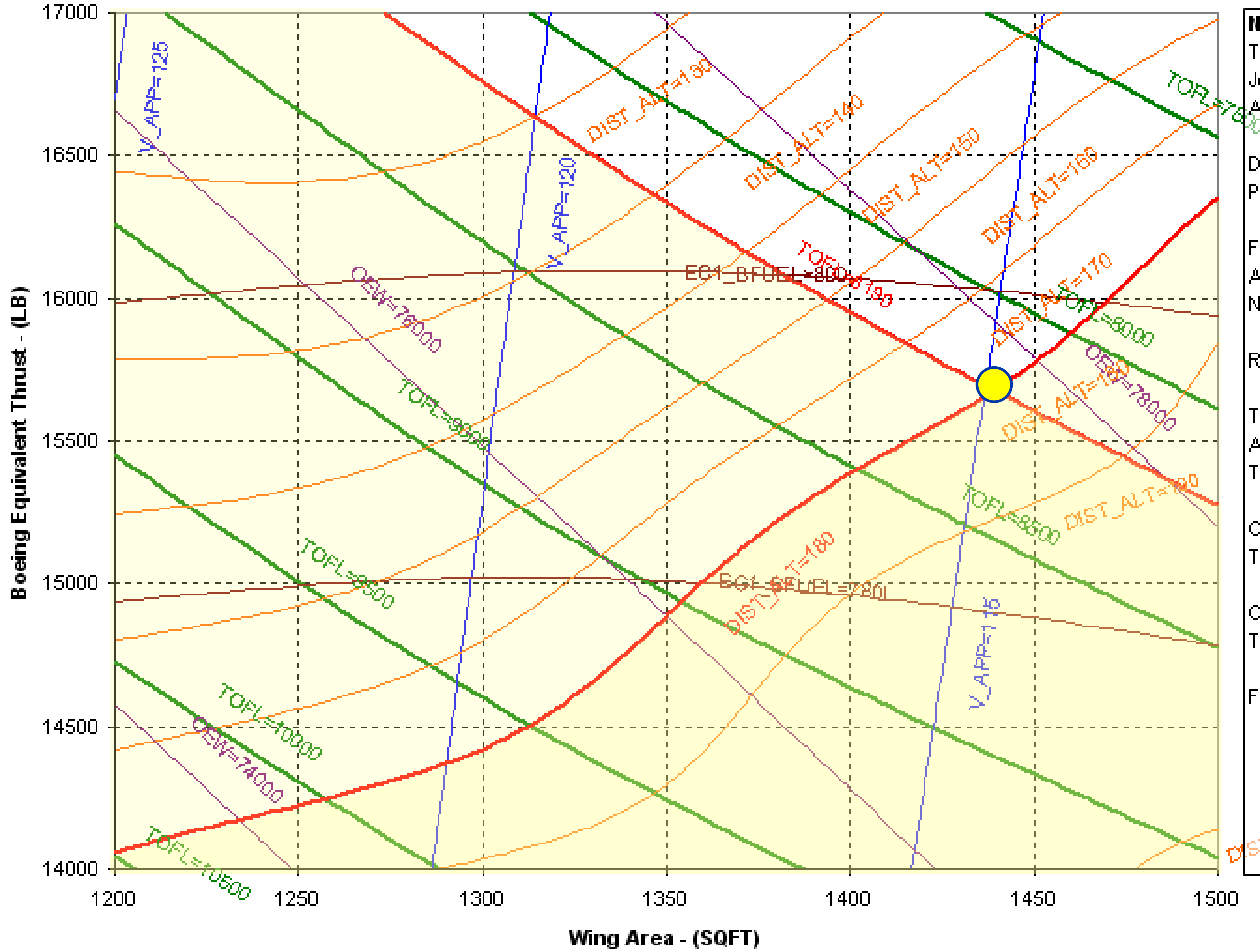
Propulsion system wt	6411	lbm
Fan diameter	70	in
Length	122	in, spinner to TRF
Performance	**Thrust, lbf**	**SFC, lbm/lbf-hr**
SLS	18,900	0.256
Rolling takeoff	14303	0.344
Top-of-climb	4229	0.534
Cruise	4025	0.528
Emissions	-58%	relative to CAEP/6

Projected Technologies
Advanced 3-D aero composite fan
Ultra-high PR compressor
Advanced low-emissions combustor
Integrated thrust reverser/variable fan nozzle
CMC turbine blades/vanes
Next-gen component aero technology
Next-gen nacelle technology
Improved shaft material
Acoustics technology suite
High DN bearings, high speed/temperature seals
TiAl materials & process technology

Refined SUGAR – Sizing

Refined SUGAR
[Airplane: 765-094, Engine: Gfan]

Product Development Study



Notes:
Time: 09/17/09 : 10:02:02
Job Number: DS-2009-022
Analyst: Conlin

Design Space Data Sheet: [Sheet7]
Plot Data Sheet: [Sheet12]

Fixed Variables:
Aspect Ratio = 11.63467
No. Passengers = 154

Range Requirement: 3500 nmi

Takeoff Field length Conditions:
Altitude: 0 ft
Temperature: 86 degF

Ceiling Conditions:
Temperature: 0 Delta ISA C

Climb Conditions:
Temperature: 15 Delta ISA C

Fuel Density: 6.50 lb/usg

Refined SUGAR – Performance

BCA – Advanced Concepts | BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

Refined SUGAR

Product Development Study

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		**SUGAR Free**	**Refined SUGAR**
PASSENGERS / CLASS		154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	184,800	139,700
MAX LANDING WEIGHT	LB	151,000	131,800
MAX ZERO FUEL WEIGHT	LB	142,000	123,800
OPERATING EMPTY WEIGHT	LB	96,000	77,800
FUEL CAPACITY REQ	USG	9,710	5,512
ENGINE MODEL		Scaled CFM56-7B27	Scaled gFan
FAN DIAMETER	IN	62	66
BOEING EQUIVLENT THRUST (BET)	LB	28,200	15,700
WING AREA / SPAN	FT^2 / FT	1429 / 122	1440 / 129
ASPECT RATIO (EFFECTIVE)		10.41	11.63
OPTIMUM CL		0.583	0.654
CRUISE L/D @ OPT CL		18.068	21.981
DESIGN MISSION RANGE	NMI	3,500	3,500
PERFORMANCE CRUISE MACH		0.785	0.70
LONG RANGE CRUISE MACH (LRC)		0.785	0.70
THRUST ICAC (MTOW, ISA)	FT	37,200	38,800
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	23 / 148	29 / 182
OPTIMUM ALTITUDE (MTOW, ISA)	FT	35,000	38,400
BUFFET ICAC (MTOW, ISA)	FT	36,200	45,200
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190	8,190
APPROACH SPEED (MLW)	KT	126	115
BLOCK FUEL / SEAT (900 NMI)	LB	92.35 (Base)	51.53 (-44.2%)

44% Fuel Burn Reduction

Refined SUGAR – gFan+ Engine

PERFORMANCE SUMMARY

Refined SUGAR

Product Development Study

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		Refined SUGAR	Refined SUGAR gFan+ Engine
PASSENGERS / CLASS		154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	139,700	139,500
MAX LANDING WEIGHT	LB	131,800	133,600
MAX ZERO FUEL WEIGHT	LB	123,800	125,600
OPERATING EMPTY WEIGHT	LB	77,800	79,600
FUEL CAPACITY REQ	USG	5,512	5,208
ENGINE MODEL		Scaled gFan	Scaled gFan+
FAN DIAMETER	IN	66	76
BOEING EQUIVLENT THRUST (BET)	LB	15,700	15,300
WING AREA / SPAN	FT^2 / FT	1440 / 129	1407 / 128
ASPECT RATIO (EFFECTIVE)		11.63	11.63
OPTIMUM CL		0.654	0.708
CRUISE L/D @ OPT CL		21.981	21.428
DESIGN MISSION RANGE	NMI	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	38,800	40,100
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	29 / 182	29 / 186
OPTIMUM ALTITUDE (MTOW, ISA)	FT	38,400	39,600
BUFFET ICAC (MTOW, ISA)	FT	45,200	44,800
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190	8,190
APPROACH SPEED (MLW)	KT	115	117
BLOCK FUEL / SEAT (900 NMI)	LB	51.53 (Base)	48.31 (-6.2%)

Advanced engine technologies yield significant benefits

Refined SUGAR – TOFL Trade

BCA – Advanced Concepts | BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

Refined SUGAR – TOFL Trade

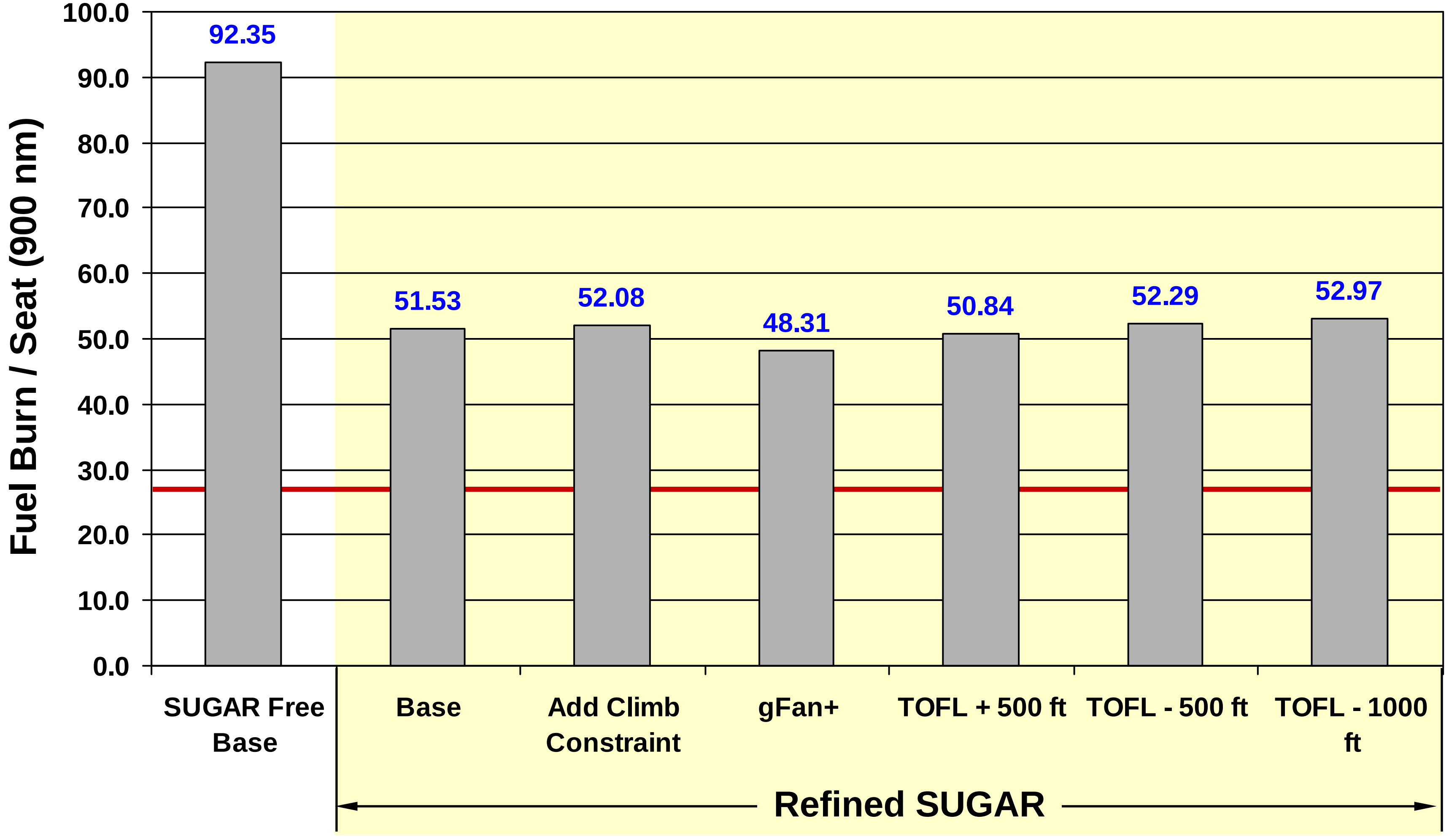
Product Development Study

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		+500 ft	Base TOFL	-500 ft	-1,000 ft
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	138,400	139,700	141,200	142,900
MAX LANDING WEIGHT	LB	130,800	131,800	132,900	134,300
MAX ZERO FUEL WEIGHT	LB	122,800	123,800	124,900	126,300
OPERATING EMPTY WEIGHT	LB	76,800	77,800	78,900	80,300
FUEL CAPACITY REQ	USG	5,457	5,512	5,571	5,615
ENGINE MODEL		Scaled gFan	Scaled gFan	Scaled gFan	Scaled gFan
FAN DIAMETER	IN	65	66	68	69
BOEING EQUIVLENT THRUST (BET)	LB	15,100	15,700	16,300	16,700
WING AREA / SPAN	FT^2 / FT	1400 / 128	1440 / 129	1490 / 132	1580 / 136
ASPECT RATIO (EFFECTIVE)		11.63	11.63	11.63	11.63
OPTIMUM CL		0.660	0.654	0.652	0.653
CRUISE L/D @ OPT CL		21.874	21.981	22.109	22.374
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70	0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	38,400	38,800	39,500	40,100
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	30 / 189	29 / 182	28 / 177	29 / 168
OPTIMUM ALTITUDE (MTOW, ISA)	FT	38,400	38,400	38,800	39,900
BUFFET ICAC (MTOW, ISA)	FT	45,100	45,200	45,700	46,800
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,680	8,190	7,690	7,190
TOFL (900 NMI MISS, SEA LEVEL, 86 DEG F)	FT	5,790	5,510	5,240	4,940
APPROACH SPEED (MLW)	KT	116	115	113	111
BLOCK FUEL / SEAT (900 NMI)	LB	50.84 (-1.3%)	51.53 (Base)	52.29 (+1.5%)	52.97 (+2.8%)

Impacts to lowering TOFL

Refined SUGAR Performance Trades Summary



Refined SUGAR – Emissions

gFan

- **41.7% of CAEP/6 (58.3% reduction relative to CAEP/6)**
- **CO_2:** 162 klbs at 900 nmi
- **CO_2 with biofuel:** 81 klbs at 900 nmi

- gFan+
  - **28% of CAEP/6 (72% reduction relative to CAEP/6)**
  - **CO_2:** 152 klbs at 900 nmi
  - **CO_2 with biofuel:** 76 klbs at 900 nmi

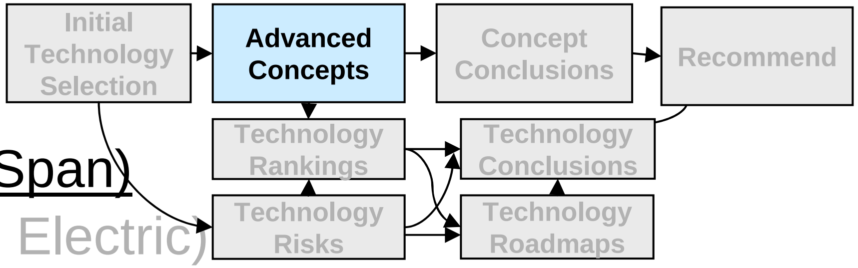
Refined SUGAR – Conclusions

- Conventional configuration benefits from N+3 advanced technologies
- Increased span and detailed wing fold design offer opportunity for improved performance as well as challenge (weight and integration)
  - *Will be shown later in comparisons section as "Super Refined SUGAR"*
- Refined SUGAR is greatly improved relative to SUGAR Free, but does not meet NASA N+3 goals

SUGAR Phase 1 Final Review

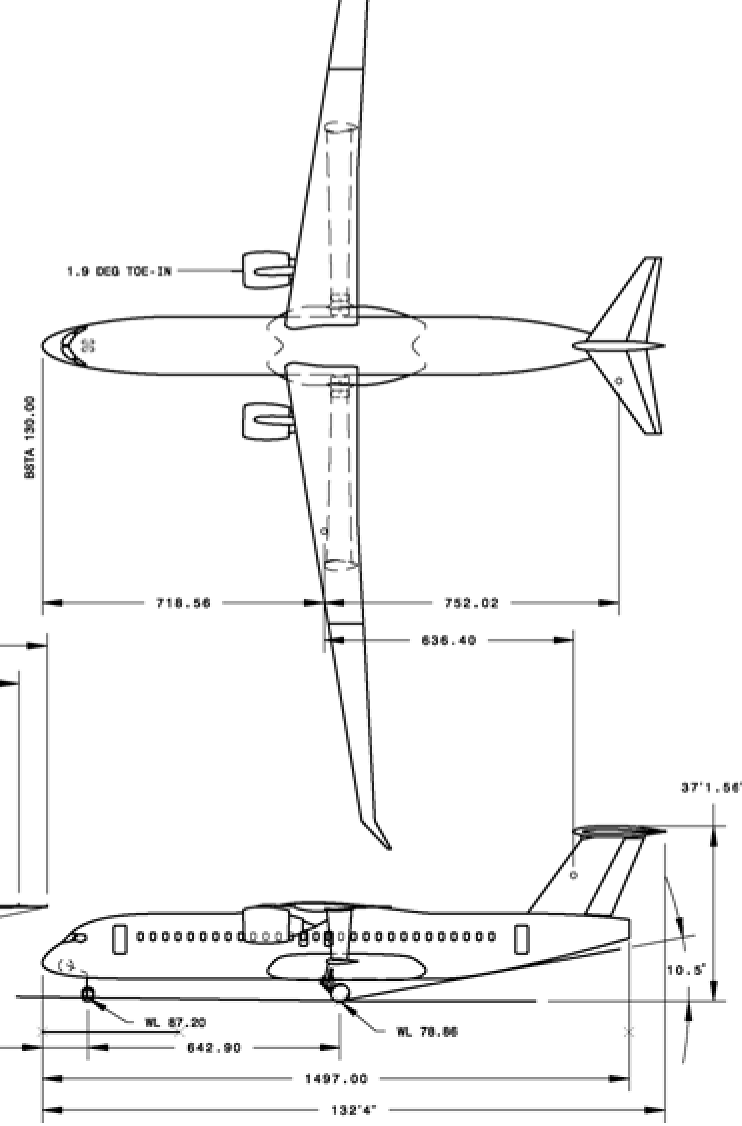
9:20

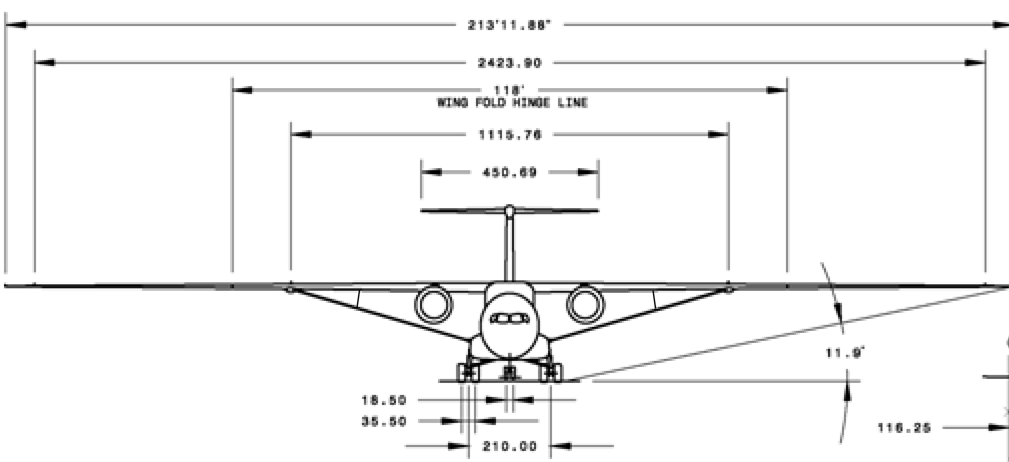
- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- **Concept Performance and Sizing from 12-Month Review**
  - SUGAR Free (N Baseline)
  - Refined SUGAR (N+3 Reference)
  - SUGAR High (N+3 Advanced High Span)
  - SUGAR Volt (N+3 Advanced Hybrid Electric)
  - SUGAR Ray (N+3 Advanced HWB Low Noise)
  - Sized Vehicle Summary & Comparisons
- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- Lunch
- Proprietary Session



SUGAR High (765-095) – Three View

	WING Wimpress	V-TAIL Trap	H-TAIL Trap
Area*	1767.20	270.30	314.35
Aspect Ratio*	23.087	1.15	4.48
Taper Ratio	0.173	0.70	0.25
MAC Inches	115.90	185.88	112.46
Dihedral (Deg.)	0.0	-	0.00
1/4 Chord Sweep (Deg.)*	8.02	33.20	30.00
Root Chord (Inches)	194.30	216.44	160.64
Tip Chord (Inches)	33.70	151.50	40.23
Span (W/O Winglet)*	2423.90	211.56	450.68
Volume Coeffec.	-	???	???





SUGAR High – Technology Description

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

Subsystem Technologies	
Power Management	Adaptive
Power Generation	Eng. Primary; APU Gnd. & Bkup.
APU	Conventional or Diesel
Actuators	EMA
Control Architecture	Maximize Use of Fiberoptics
Thermal Technology	Lightweight
Electro Magnetic Effects / Lightning	More Tolerant Systems & Dual Use Structure
Fuel	Low Sulfur Jet-A, Synthetic or Biofuels
Flight Avionics	NextGen ATM Capable
Wiring	High Conductivity, Lightweight
Computing Networks	Integrated

Aero Technologies	
Laminar Flow	Passive/Natural and Active Where Appropriate
Riblets	Fuselageand Wing Where Appropriate
Excrescence Drag	Multi-Functional Structures, Reduced Fasteners, Reduced Flap Fairings
Empennage	Relaxed Static Stability & Increased C_{LMax}
Airfoil Technology	Advanced Supercritical
Additional Technologies	Low Interference Nacelles Low Drag Strut Integration

Structural Technologies	
Materials / Manufacturing	Adv. Composites incl. Hybrid Polymer, Adv. Metals, Adv. Joining, Adv. Ceramics
Health Management	On-board Structurally Integrated SHM, Advanced NDE/NDI
Loads & Environments	Maximize Flight Control Integration, Active/Passive Aeroelastic Response for Load Control
Design & Criteria	Reliability Based, Robust/Unitized, Multi-Functional Structures, Support for NLF
Adaptive Structures for Control Systems	Conformal, Gapless, Adaptive, Spanwise Load Control
Energy Management	Structurally Integrated Thermal and Electrical Energy Management
Coatings	Enable Lightweight Materials, Energy Harvesting, Thermal Management, Drag Reduction
Interiors	More Lightweight
Additional Structures Technologies	Lightweight Wing Folds, Adv. Lightweight High Lift Systems, Adv. Material Forms

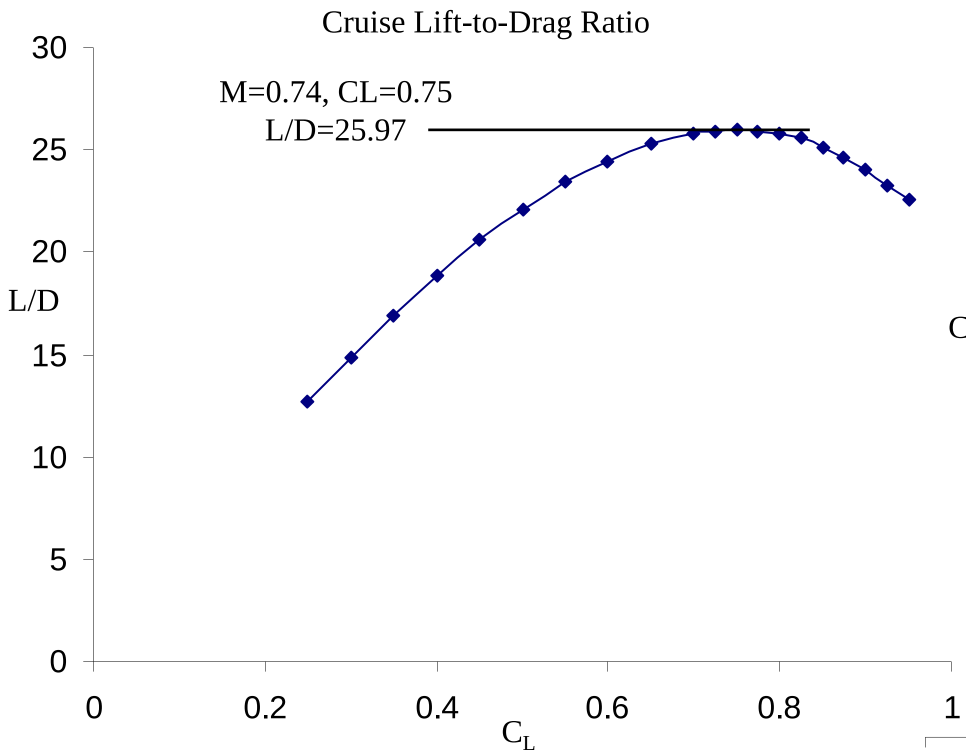
Propulsion Technologies	
Engine Cycle	Very high BPR turbofan with Advanced engine technologies
Combustor	Variable Flow Splits, Ultra-compact low emissions combustor
Materials	Refined SUGAR + MMC's, Advanced CMC mat'ls & processes
Acoustic	Refined SUGAR + Active noise control/fluidics, Non-Ax symmetric nozzles, Unique/shielded installations
Mechanical	Additional advanced systems (as needed)

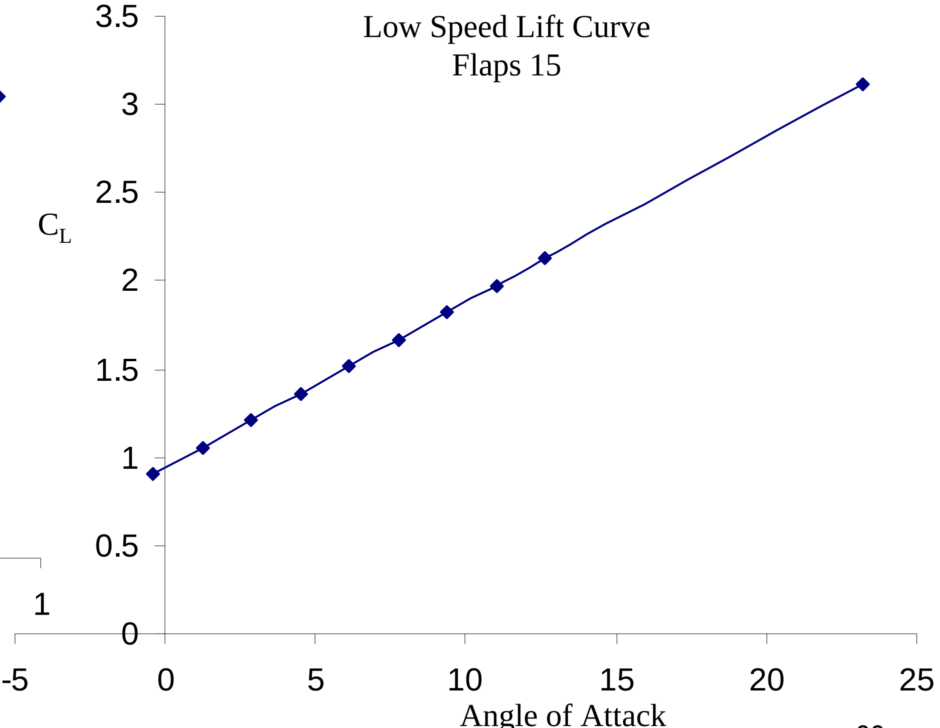
SUGAR High – Aero

BCA – Advanced Concepts

BR&T – Platform Performance Technology

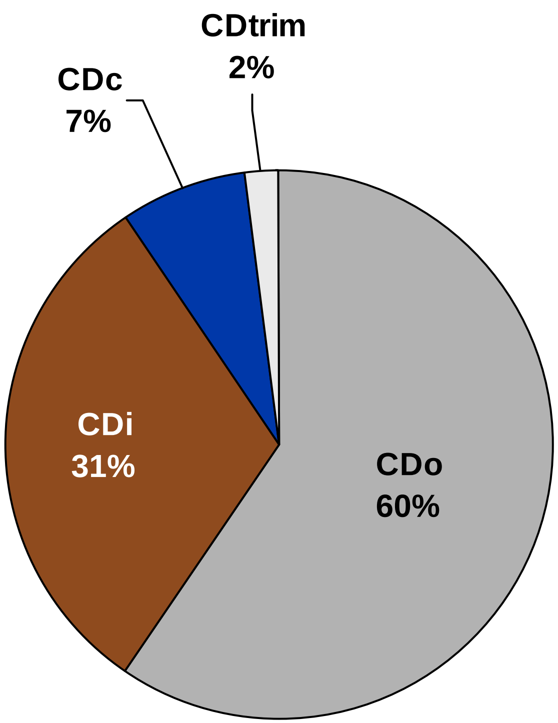
- Laminar flow over wing, vertical tail, and strut-bracing
- Riblets on fuselage and turbulent portion of wing
- Advanced Supercritical Airfoils
- Improved excrescence
- Low interference nacelles
- Low drag strut integration





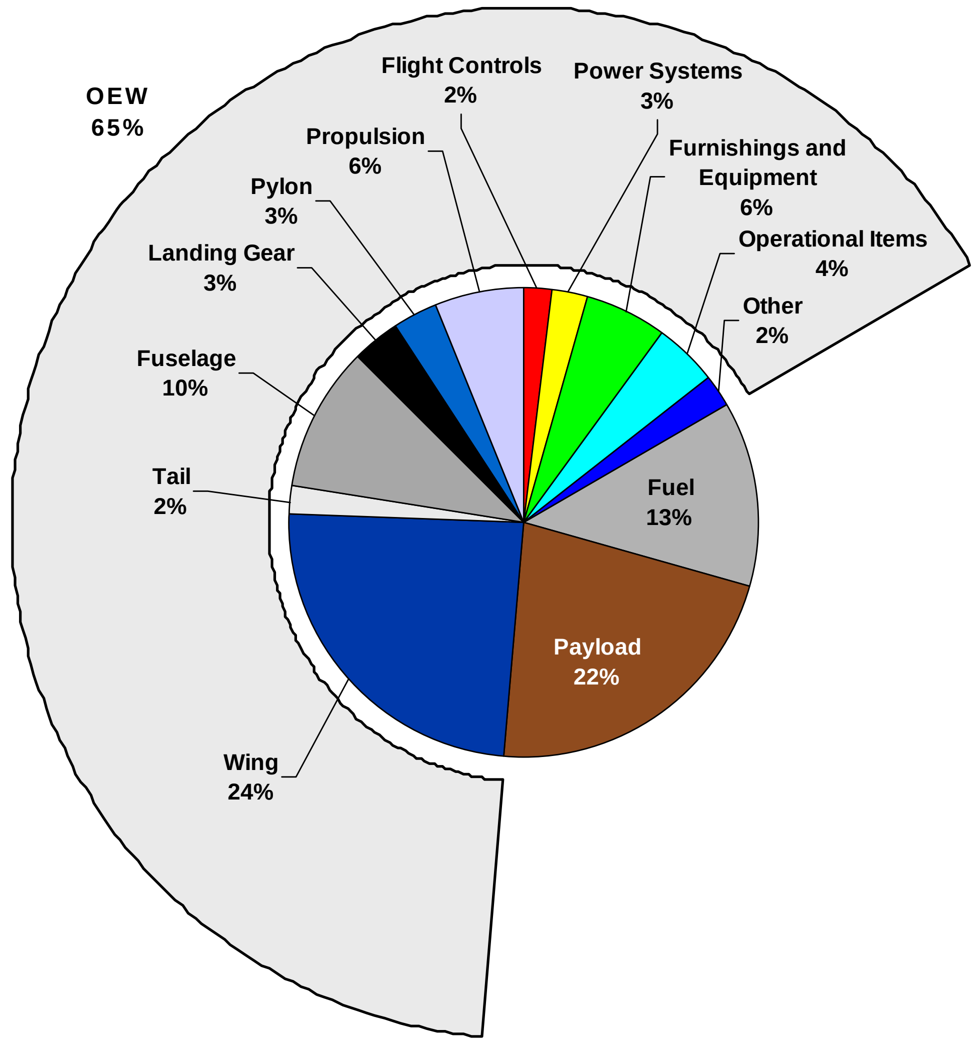
SUGAR High and SUGAR Volt
High Speed Aerodynamics

SUGAR High and SUGAR Volt	
SREF (FT**2)	1700
FN (LBS)	17663
AR	24
SWEEP (DEG)	8
T/C-AVE	0.1119
AIRFOIL TYPE	ADVANCED SUPERCRITICAL
S-HORIZ (FT**2)	314.293
S-VERT (FT**2)	270.003
F BUILD-UP (FT2)**	
WING	12.1223
WINGLET	2.6111
HORIZONTAL	1.8454
VERTICAL	1.6581
N&P	3.1500
CANOPY	0.0405
GEAR PODS	4.0542
ETC BEFORE SUB	-6.6897
EXCRESCENCE	1.9001
UPSWEEP	0.6012
WING TWIST	0.5219
STRAKES	0.0000
ETC AFTER SUB	-2.5913
FUSELAGE BUMP	1.0350
F-TOTAL (FT2)**	**29.1249**
E-VISC	**0.824**
CRUISE CD BUILD-UP	
M-CRUISE	0.74
CL-CRUISE	0.75
CRUISE ALTITUDE	44000
CD0	0.01713
CDI	0.00905
CDC	0.00212
CDTRIM	0.00058
CDTOT	**0.02888**
L/D	**25.970**



SUGAR High – Mass Properties

GROUP	WEIGHT (LB)	
WING	**36,798**	
BENDING MATERIAL		20,602
SPAR WEBS		3,434
RIBS AND BULKHEADS		3,434
AERODYNAMIC SURFACES		4,925
SECONDARY STRUCTURE		4,403
TAIL	**3,157**	
FUSELAGE	**16,327**	
LANDING GEAR	**5,595**	
NACELLE & PYLON (Strut)	**5,036**	
WING STRUT & INSTALLATION	**2,800**	
PROPULSION	**9,984**	
ENGINES		9,156
FUEL SYSTEM		828
FLIGHT CONTROLS	**2,873**	
COCKPIT CONTROLS		252
SYSTEM CONTROLS		2,621
POWER SYSTEMS	**4,138**	
AUXILIARY POWER PLANT		1,014
HYDRAULICS		827
ELECTRICAL		2,297
INSTRUMENTS	**773**	
AVIONICS & AUTOPILOT	**1,504**	
FURNISHINGS & EQUIPMENT	**9,115**	
AIR CONDITIONING	**1,441**	
ANTI-ICING	**141**	
MANUFACTURER'S EMPTY WEIGHT (MEW)	**99,682**	
OPERATIONAL ITEMS	7,207	
OPERATIONAL EMPTY WEIGHT (OEW)	**106,889**	
USABLE FUEL	20,774	
PAYLOAD	36,190	
TAKEOFF GROSS WEIGHT (TOGW)	**163,853**	



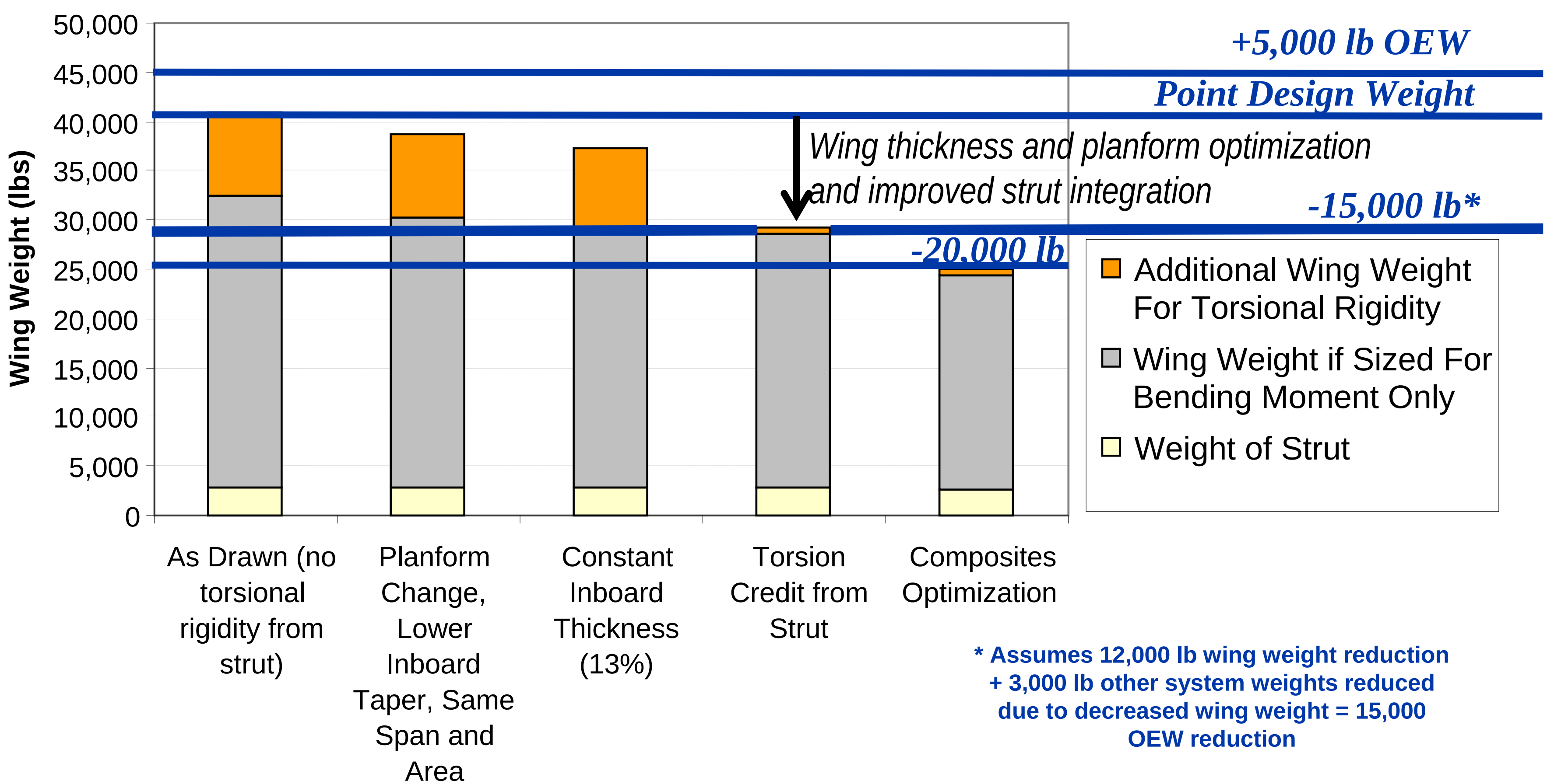
SUGAR High – Mass Properties

- **The most difficult challenge faced by the design team for this project was determining the wing weight for the SUGAR High**

- **Wing weight uncertainty driven by assumptions:**
  - Wing Bending Moment Relief from Strut
  - Wing Torsional Stiffness Credit from Strut
  - Active alleviation for maneuver, flutter, and gust loads
  - Wing layout, materials, and manufacturing considerations
  - Wing folds methodology and design criteria

- **To estimate the potential impact of wing optimization and advanced technologies, we have looked at a wide range of wing weights in our trades and sensitivities. For comparisons between concepts we have identified a "point design" weight using consistent weight assumptions and methods.**

Wing Weight Assumptions & Trade



* Assumes 12,000 lb wing weight reduction + 3,000 lb other system weights reduced due to decreased wing weight = 15,000 OEW reduction

Minimal aero impact is expected from these changes

- **Lower fidelity methods used to determine these weight reduction opportunities**
- **We have included this entire range of weights in our comparison section**

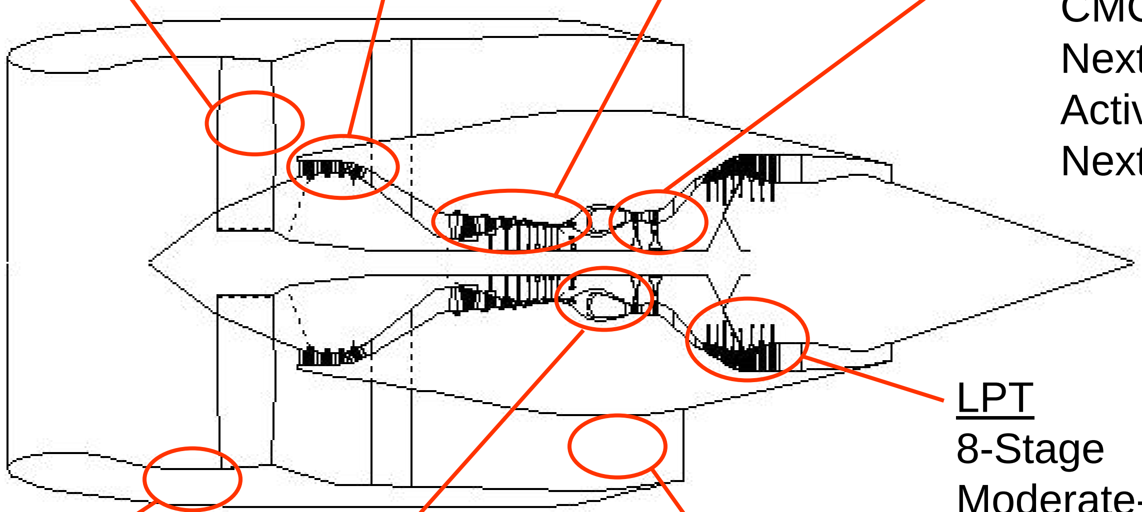
N+3 Advanced Engine Architecture (gFan+)

Advanced Composite Fan
1.35 PR, 77.3” fan
Advanced 3-D aero design
Sculpted features, low noise
Thin, durable edges

4-Stage Booster

Ultra-high PR core compressor
59 OPR, 9 stages
Active clearance control

HPT
2-Stage, uncooled
CMC nozzles + blades
Next-gen CMC
Active purge control
Next-gen disk material



LPT
8-Stage
Moderate-high stage loading
CMC blades/vanes (weight)

Advanced nacelle
Highly Integrated
Minimum OD
Unitized composite

Advanced combustor

Integrated thrust reverser/VFN
Highly variable fan nozzle

N+3 Reference Engine Description (gFan+)

BCA – Advanced Concepts | BR&T – Platform Performance Technology

▪ "gFan+" Architectural concept

- Boosted 2-spool SFTF, 59 OPR, 13 BPR
- OPR lower than "gFan" due to lower FPR
- Modest hot section temperatures, extensive use of CMCs
- Compatible with emissions goals/advanced combustor

Propulsion system wt	7096	lbm
Fan diameter	77	in
Length	122	in, spinner to TRF
Performance	**Thrust, lbf**	**SFC, lbm/lbf-hr**
SLS	18800	0.211
Rolling takeoff	13385	0.301
Top-of-climb	3145	0.475
Cruise	3028	0.470
Emissions	-72%	relative to CAEP/6

Projected Technologies
Advanced 3-D aero composite fan
Ultra-high PR compressor
Advanced low-emissions combustor
Integrated thrust reverser/variable fan nozzle
Next-gen CMC HPT vanes, blades, and shrouds
Next-gen component aero technology
Next-gen nacelle technology
Improved shaft material
Acoustics technology suite
High DN bearings, high speed/temperature seals
TiAl materials & process technology
Advanced hot section disk material
Active purge control
Advanced CMC blade and vane features
Closed-loop, fast-response turbine ACC

SUGAR High – Performance

BCA – Advanced Concepts   BR&T – Platform Performance Technology

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

PERFORMANCE SUMMARY

SUGAR High

Product Development Study

MODEL Sizing Level		SUGAR Free	Refined SUGAR	SUGAR High
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	184,800	139,700	176,800
MAX LANDING WEIGHT	LB	151,000	131,800	167,300
MAX ZERO FUEL WEIGHT	LB	142,000	123,800	159,300
OPERATING EMPTY WEIGHT	LB	96,000	77,800	113,300
FUEL CAPACITY REQ	USG	9,710	5,512	5,754
ENGINE MODEL		Scaled CFM56-7B27	Scaled gFan	Scaled gFan+
FAN DIAMETER	IN	62	66	86
BOEING EQUIVLENT THRUST (BET)	LB	28,200	15,700	19,600
WING AREA / SPAN	FT^2 / FT	1429 / 122	1440 / 129	1722 / 215
ASPECT RATIO (EFFECTIVE)		10.41	11.63	26.94
OPTIMUM CL		0.583	0.654	0.828
CRUISE L/D @ OPT CL		18.068	21.981	25.934
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.785	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.785	0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	37,200	38,800	43,300
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	23 / 148	29 / 182	29 / 182
OPTIMUM ALTITUDE (MTOW, ISA)	FT	35,000	38,400	42,100
BUFFET ICAC (MTOW, ISA)	FT	36,200	45,200	44,000
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190	8,190	8,190
APPROACH SPEED (MLW)	KT	126	115	115
BLOCK FUEL / SEAT (900 NMI)	LB	92.35 (Base)	51.53 (-44.2%)	56.43 (-38.9%)

SUGAR High Trades – Wing Weight

BCA – Advanced Concepts BR&T – Platform Performance Technology

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

PERFORMANCE SU
SUGAR High

Wing weight assumptions are key to SUGAR High performance

MODEL Sizing Level		*+5,000 lb**	Base	-5,000 lb	-10,000 lb	-15,000 lb**	-20,000 lb
PASSENGERS / CLASS		*154 / Dual*	154 / Dual	154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT **MAX LANDING WEIGHT** **MAX ZERO FUEL WEIGHT** **OPERATING EMPTY WEIGHT** **FUEL CAPACITY REQ**	LB LB LB LB USG	*189,200* *177,900* *169,900* *123,900* *6,038*	176,800 167,300 159,300 113,300 5,754	164,400 156,700 148,700 102,700 5,470	152,100 146,200 138,200 92,200 5,184	140,100 136,000 128,000 82,000 4,928	128,200 125,800 117,800 71,800 4,658
ENGINE MODEL **FAN DIAMETER** **BOEING EQUIVLENT THRUST (BET)**	 IN LB	*Scaled gFan+* *89* *20,800*	Scaled gFan+ 86 19,600	Scaled gFan+ 83 18,400	Scaled gFan+ 80 17,200	Scaled gFan+ 78 16,200	Scaled gFan+ 75 15,000
WING AREA / SPAN **ASPECT RATIO (EFFECTIVE)** **OPTIMUM CL** **CRUISE L/D @ OPT CL**	FT^2 / FT	*1866 / 224* *26.94* *0.825* *26.426*	1722 / 215 26.94 0.828 25.934	1578 / 206 26.94 0.831 25.442	1441 / 197 26.94 0.836 24.909	1292 / 187 26.94 0.865 24.161	1153 / 176 26.94 0.877 23.45
DESIGN MISSION RANGE **PERFORMANCE CRUISE MACH** **LONG RANGE CRUISE MACH (LRC)** **THRUST ICAC (MTOW, ISA)** **TIME / DIST (MTOW, 35k FT, ISA)** **OPTIMUM ALTITUDE (MTOW, ISA)** **BUFFET ICAC (MTOW, ISA)** **TOFL (MTOW, SEA LEVEL, 86 DEG F)** **APPROACH SPEED (MLW)**	NMI FT NMI / NMI FT FT FT KT	*3,500* *0.70* *0.70* *43,500* *29 / 184* *42,300* *44,300* *8,190* *114*	3,500 0.70 0.70 43,300 29 / 182 42,100 44,000 8,190 115	3,500 0.70 0.70 43,100 28 / 180 41,900 43,700 8,180 116	3,500 0.70 0.70 43,000 28 / 180 41,700 43,500 8,180 118	3,500 0.70 0.70 42,900 28 / 181 41,900 42,900 8,150 120	3,500 0.70 0.70 42,600 28 / 180 41,600 42,400 8,230 122
BLOCK FUEL / SEAT (900 NMI)	LB	*59.72 (+5.8%)*	56.43 (Base)	53.14 (-5.8%)	49.84 (-11.7%)	46.78 (-17.1%)	43.55 (-22.8%)

** Extrapolated*

*** Used as base for some trade studies*

SUGAR High Trades – Open Fan

BCA – Advanced Concepts | BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR High – Open Fan Trade

Product Development Study

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL **Sizing Level**		**Ducted Fan**	**With Open Fan**
PASSENGERS / CLASS		154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	140,100	144,900
MAX LANDING WEIGHT	LB	136,000	143,100
MAX ZERO FUEL WEIGHT	LB	128,000	135,100
OPERATING EMPTY WEIGHT	LB	82,000	89,100
FUEL CAPACITY REQ	USG	4,928	4,566
ENGINE MODEL		Scaled gFan+	Scaled gFan+ Open Fan
FAN DIAMETER	IN	78	~139
BOEING EQUIVLENT THRUST (BET)	LB	16,200	16,500
WING AREA / SPAN	FT^2 / FT	1292 / 187	1365 / 192
ASPECT RATIO (EFFECTIVE)		26.94	26.94
OPTIMUM CL		0.865	0.838
CRUISE L/D @ OPT CL		24.161	24.794
DESIGN MISSION RANGE	NMI	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	42,900	43,000
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	28 / 181	28 / 177
OPTIMUM ALTITUDE (MTOW, ISA)	FT	41,900	41,600
BUFFET ICAC (MTOW, ISA)	FT	42,900	43,300
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,150	8,190
APPROACH SPEED (MLW)	KT	120	120
BLOCK FUEL / SEAT (900 NMI)	LB	46.78 (Base)	43.39 (-7.2%)

Use of open fan results in additional fuel burn reduction

SUGAR High – TOFL Trade

BCA – Advanced Concepts BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR High – TOFL Trade

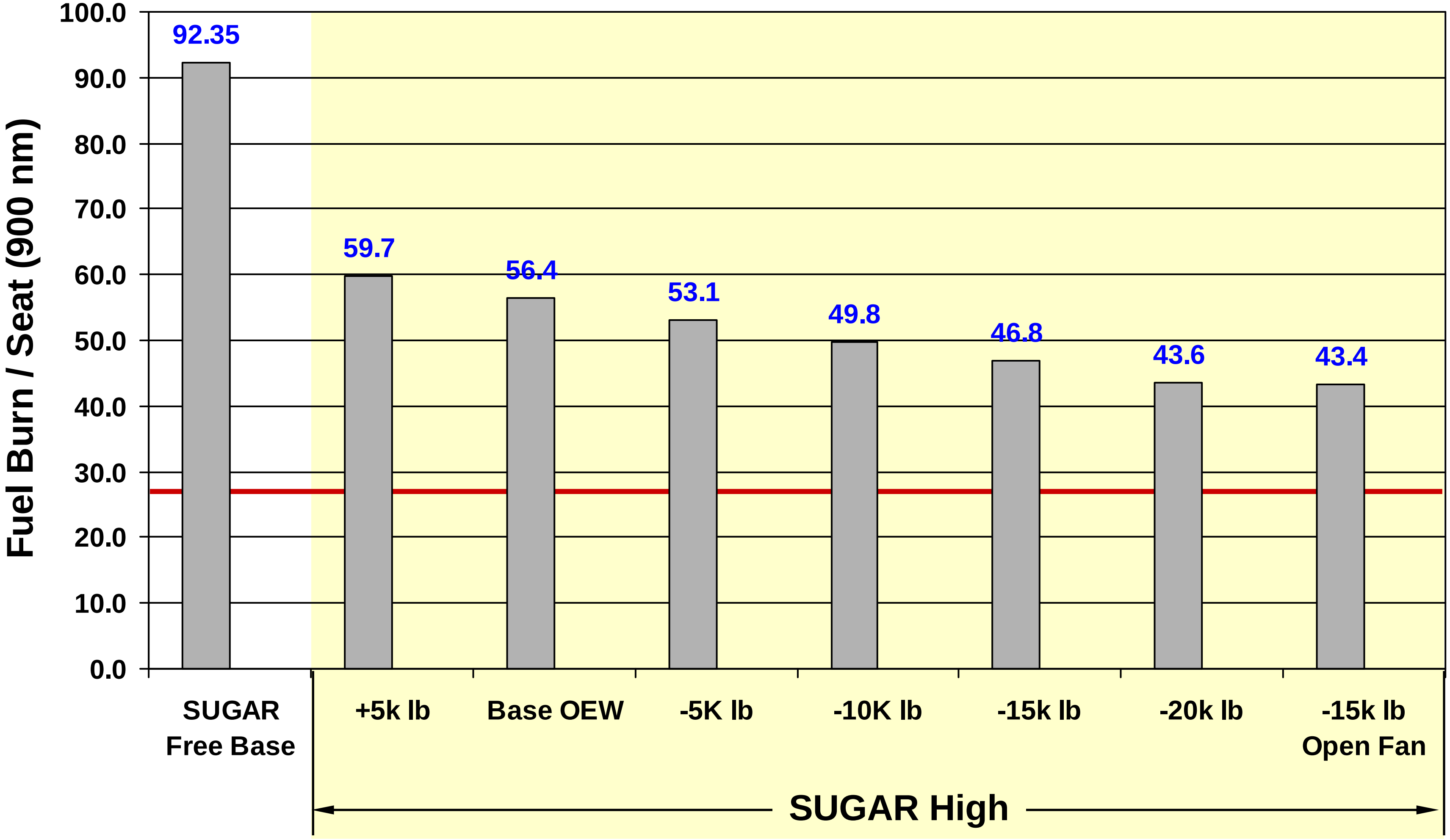
Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

TOFL Sensitivities have been calculated

MODEL Sizing Level		+500 ft	Base	-500 ft	-1000 ft
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	138,900	140,100	142,100	144,200
MAX LANDING WEIGHT	LB	134,800	136,000	137,700	139,400
MAX ZERO FUEL WEIGHT	LB	126,800	128,000	129,700	131,400
OPERATING EMPTY WEIGHT	LB	80,800	82,000	83,700	85,400
FUEL CAPACITY REQ	USG	4,907	4,928	4,968	5,032
ENGINE MODEL		Scaled gFan+	Scaled gFan+	Scaled gFan+	Scaled gFan+
FAN DIAMETER	IN	77	78	79	80
BOEING EQUIVLENT THRUST (BET)	LB	15,700	16,200	16,600	17,300
WING AREA / SPAN	FT^2 / FT	1231 / 182	1292 / 187	1365 / 192	1431 / 196
ASPECT RATIO (EFFECTIVE)		26.94	26.94	26.94	26.94
OPTIMUM CL		0.873	0.865	0.843	0.839
CRUISE L/D @ OPT CL		23.892	24.161	24.508	24.742
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70	0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	42,300	42,900	43,400	44,000
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	28 / 178	28 / 181	28 / 179	28 / 178
OPTIMUM ALTITUDE (MTOW, ISA)	FT	41,200	41,900	42,200	42,700
BUFFET ICAC (MTOW, ISA)	FT	42,100	42,900	43,700	44,400
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,690	8,150	7,680	7,190
TOFL (900 NMI MISS, SEA LEVEL, 86 DEG F)	FT	6,290	5,940	5,630	5,310
APPROACH SPEED (MLW)	KT	122	120	117	115
BLOCK FUEL / SEAT (900 NMI)	LB	46.27 (-1.1%)	46.78 (Base)	47.45 (+1.4%)	48.32 (+3.3%)

SUGAR High Performance Trades Summary



SUGAR High – Emissions

- gFan+
  - **28% of CAEP/6 (72% reduction relative to CAEP/6)**
  - **CO_2:** 178 klbs at 900 nmi
  - **CO_2: with biofuel:** 89 klbs at 900 nmi

- gFan+ Open Fan
  - **25%* of CAEP/6 (75% reduction relative to CAEP/6)**
  - **CO_2:** 158 klbs at 900 nmi
  - **CO_2: with biofuel:** 79 klbs at 900 nmi

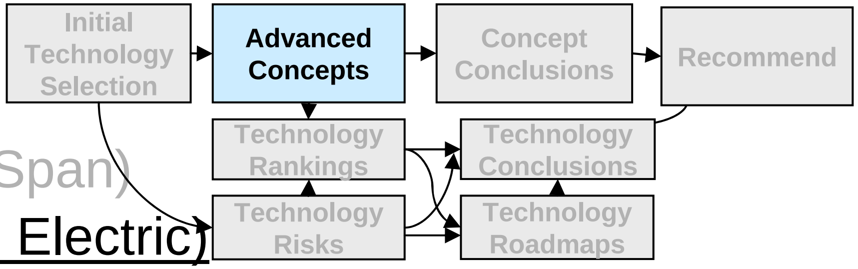
* *Assumes 11% better performance (emissions not verified by GE)*

SUGAR High Conclusions

- **Wing fold allowed additional span**
  - Risk: wing weight, drag of joint and mechanism
- **Wing strut reduces wing weight for equivalent spans**
  - Risk: wing weight, drag of strut
- **Open fan may allow additional fuel burn reduction**
  - Risk: drag including impact on wing due to loss of laminar flow, noise
- **SUGAR High does not meet NASA N+3 fuel burn goals. Fuel burn may be better or worse than a conventional configuration (Refined SUGAR), depending on wing weight achieved.**
- **SUGAR High with Open Fan may meet NOx goals**

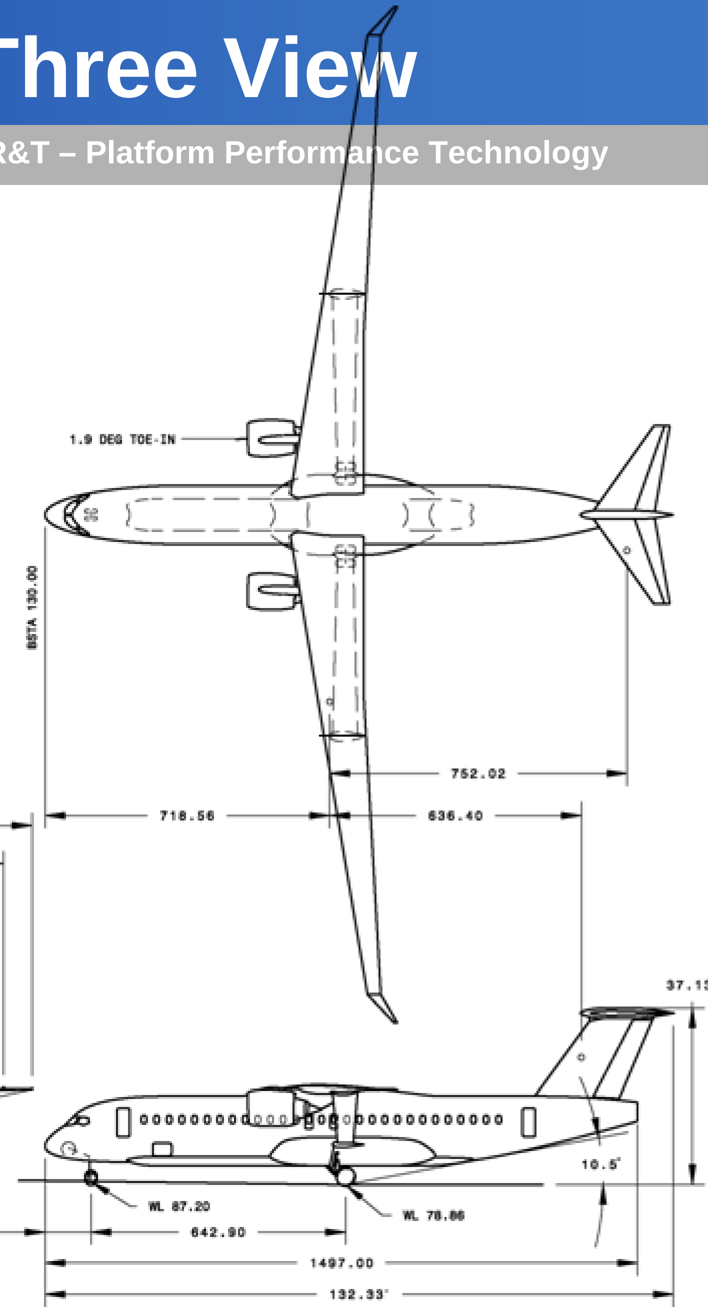
9:40

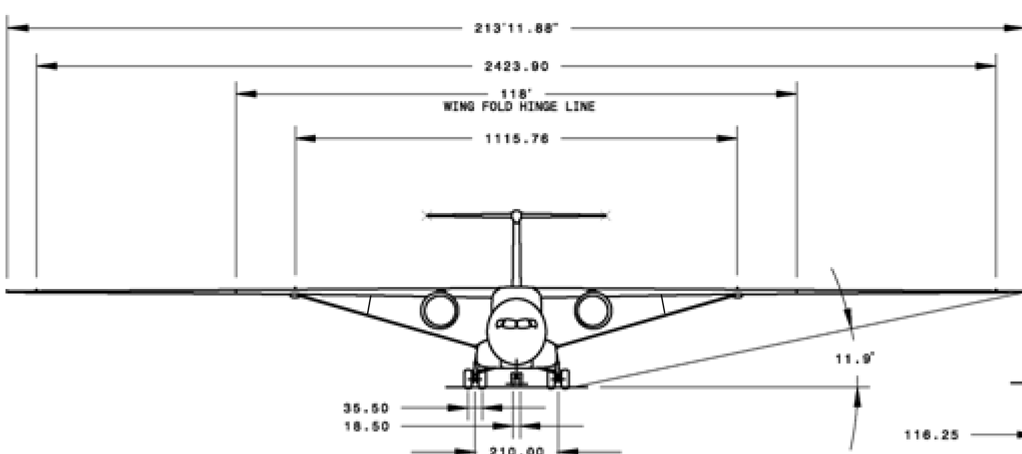
- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- **Concept Performance and Sizing from 12-Month Review**
  - SUGAR Free (N Baseline)
  - Refined SUGAR (N+3 Reference)
  - SUGAR High (N+3 Advanced High Span)
  - <u>SUGAR Volt (N+3 Advanced Hybrid Electric)</u>
  - SUGAR Ray (N+3 Advanced HWB Low Noise)
  - Sized Vehicle Summary & Comparisons
- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- Lunch
- Proprietary Session



SUGAR Volt (765-096) – Three View

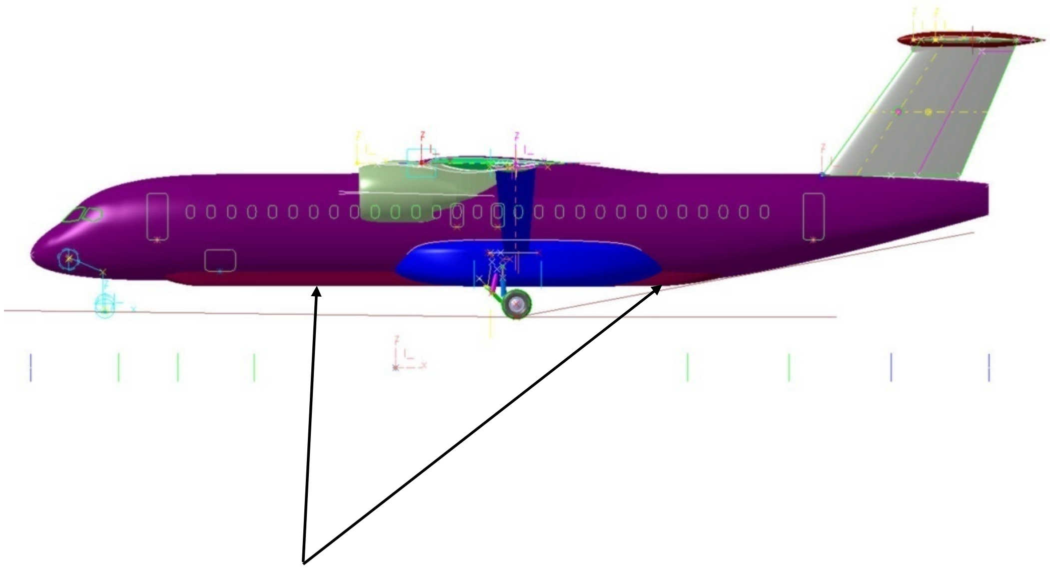
	WING Wimpress	V-TAIL Trap	H-TAIL Trap
Area*	1767.20	270.30	314.35
Aspect Ratio*	23.087	1.15	4.48
Taper Ratio	0.173	0.70	0.25
MAC Inches	115.90	185.88	112.46
Dihedral (Deg.)	0.0	-	0.00
1/4 Chord Sweep (Deg.)*	8.02	33.20	30.00
Root Chord (Inches)	194.30	216.44	160.64
Tip Chord (Inches)	33.70	151.50	40.23
Span (W/O Winglet)*	2423.90	211.56	450.68
Volume Coeffec.	-	???	???





SUGAR Volt - Configuration

- Electric / turbine hybrid propulsion variant of SUGAR High
- Modular / removable batteries mounted in fairing along fuselage



Removable Modular Battery Pack

SUGAR Volt – Technology Description

BCA – Advanced Concepts

Subsystem Technologies	
Power Management	Adaptive
Power Generation	Eng. Primary; APU Gnd. & Bkup.
APU	Conventional or Diesel
Actuators	EMA
Control Architecture	Maximize Use of Fiberoptics
Thermal Technology	Lightweight
Electro Magnetic Effects / Lightning	More Tolerant Systems & Dual Use Structure
Fuel	Low Sulfur Jet-A, Synthetic or Biofuels
Flight Avionics	NextGen ATM Capable
Wiring	High Conductivity, Lightweight
Computing Networks	Integrated

Aero Technologies	
Laminar Flow	Passive/Natural and Active Where Appropriate
Riblets	Fuselageand Wing Where Appropriate
Excrescence Drag	Multi-Functional Structures, Reduced Fasteners, Reduced Flap Fairings
Empennage	Relaxed Static Stability & Increased C_{LMax}
Airfoil Technology	Advanced Supercritical
Additional Technologies	Low Interference Nacelles Low Drag Strut Integration

BR&T – Platform Performance Technology

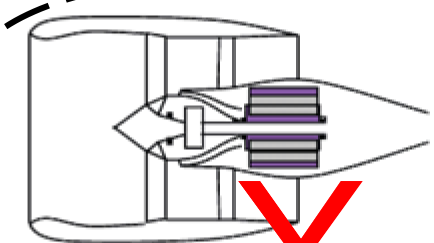
Structural Technologies	
Materials / Manufacturing	Adv. Composites incl. Hybrid Polymer, Adv. Metals, Adv. Joining, Adv. Ceramics
Health Management	On-board Structurally Integrated SHM, Advanced NDE/NDI
Loads & Environments	Maximize Flight Control Integration, Active/Passive Aeroelastic Response for Load Control
Design & Criteria	Reliability Based, Robust/Unitized, Multi-Functional Structures, Support for NLF
Adaptive Structures for Control Systems	Conformal, Gapless, Adaptive, Spanwise Load Control
Energy Management	Structurally Integrated Thermal and Electrical Energy Management
Coatings	Enable Lightweight Materials, Energy Harvesting, Thermal Management, Drag Reduction
Interiors	More Lightweight
Additional Structures Technologies	Lightweight Wing Folds, Adv. Lightweight High Lift Systems, Adv. Material Forms

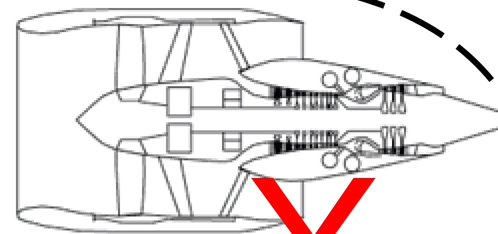
Propulsion Technologies	
Engine Cycle	Electric/Fuel Cell/Gas Turbine Hybrid (SUGAR High Tech Level)
Combustor	SUGAR High (+ on fuel cell reformer for fFan)
Materials	SiC MOSFET, motor controller, lightweight magnetics & ferrites, CMC's
Acoustic	SUGAR High
Mechanical	SUGAR High

SUGAR Volt is Derived from SUGAR High

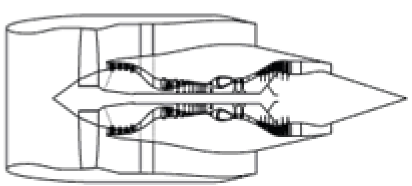
- **Same as SUGAR High Except:**
  - Propulsion system weight increased to 10,475 lbs
  - Added battery weight dependent on range (20,900 lbs at 900 nmi for base airplane)
  - Battery mounting weight 5,000 lbs
  - Wire weight 1,000 lbs
  - 2.5 cts drag for battery fairing
  - Low wing weight version of SUGAR High wing
- **Note that SUGAR Volt hybrid electric engine and power system could be applied to other configurations (Refined SUGAR or SUGAR Ray)**

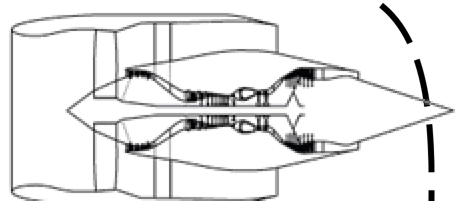
SUGAR Volt Engine Trades

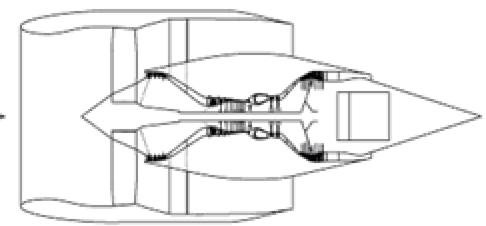




	"CFM56"	"eFan"	"fFan"
	Conventional GT	All-electric	GT-fuel cell hybrid
Airframe	SUGAR Free	SUGAR Volt	SUGAR Volt
Fan diameter / BPR	61" / 5	90" / 19	89" / ~10
Thrust (SLS/+27)	27,000 lbf	25,500 lbf	- - -
Cruise SFC	Base	-100%	-15-25% class
Propulsion system weight	Base	7,000 lb class	15-20K lb class
Emissions (relative to CAEP/6)	Base	-100%	TBD







Selected

	"gFan"	"gFan+"	"hFan"
	Gas turbine	Advanced GT	GT-electric hybrid
Airframe	Refined SUGAR	SUGAR High	SUGAR Volt
Fan diameter / BPR	70" / 9	77" / 13	89" / 18
Thrust (SLS/+27)	18,900 lbf	18,900 lbf	25,600 lbf
Cruise SFC	-21%	-28%	-28% GT mode (–100% elec. Mode)
Propulsion system weight	6411 lb	7096 lb	10475 lb
Emissions (relative to CAEP/6)	-58%	-72%	better than –72%

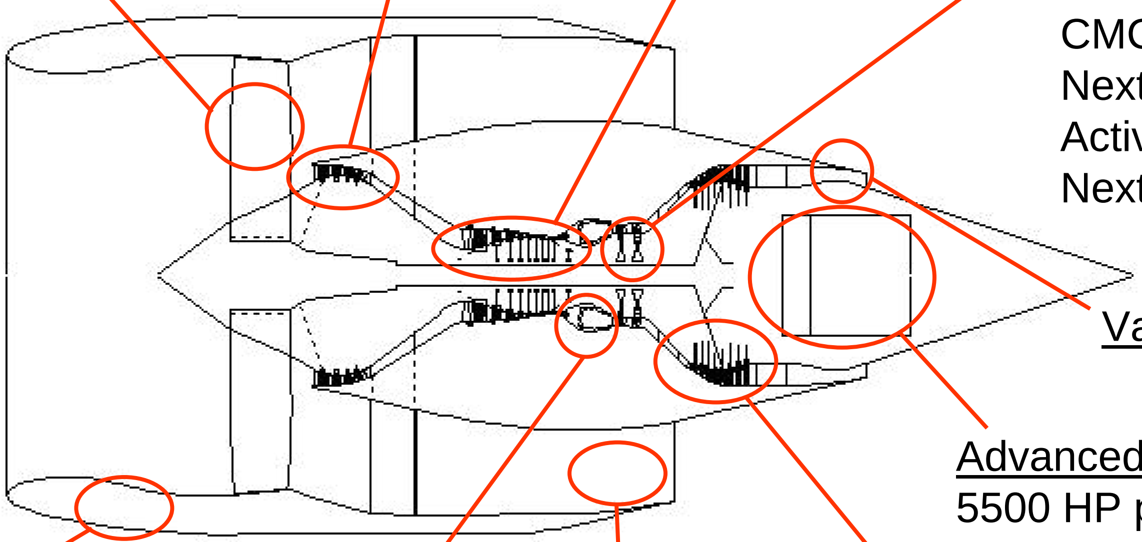
N+3 Advanced Engine Architecture (hFan)

<u>Advanced Composite Fan</u>
1.35 PR, 89.4” fan
Advanced 3-D aero design
Sculpted features, low noise
Thin, durable edges

<u>4-Stage Booster</u>

<u>Ultra-high PR core compressor</u>
59 OPR, 9 stages
Active clearance control

<u>HPT</u>
2-Stage
CMC nozzles + blades
Next-gen ceramic
Active purge control
Next-gen disk material



<u>Variable core nozzle</u>

<u>Advanced Motor & Gearbox</u>
5500 HP power output
Advanced gear box

<u>Advanced nacelle</u>
Slender OD
Unitized composite
Advanced acoustic features

<u>Advanced combustor</u>

<u>Integrated thrust reverser/VFN</u>
Highly variable fan nozzle

<u>LPT</u>
8-Stage
Highly Loaded Stages
CMC blades/vanes (weight)

N+3 Reference Engine Description (hFan)

- **"hFan" Architectural concept**
  - Boosted 2-spool SFTF, 59 OPR, 18 BPR
  - Core common to "gFan+"
  - Power to drive larger fan provided by electric subsystem

Propulsion system wt	10475	lbm
Fan diameter	89	in
Length	156	in, spinner to motor

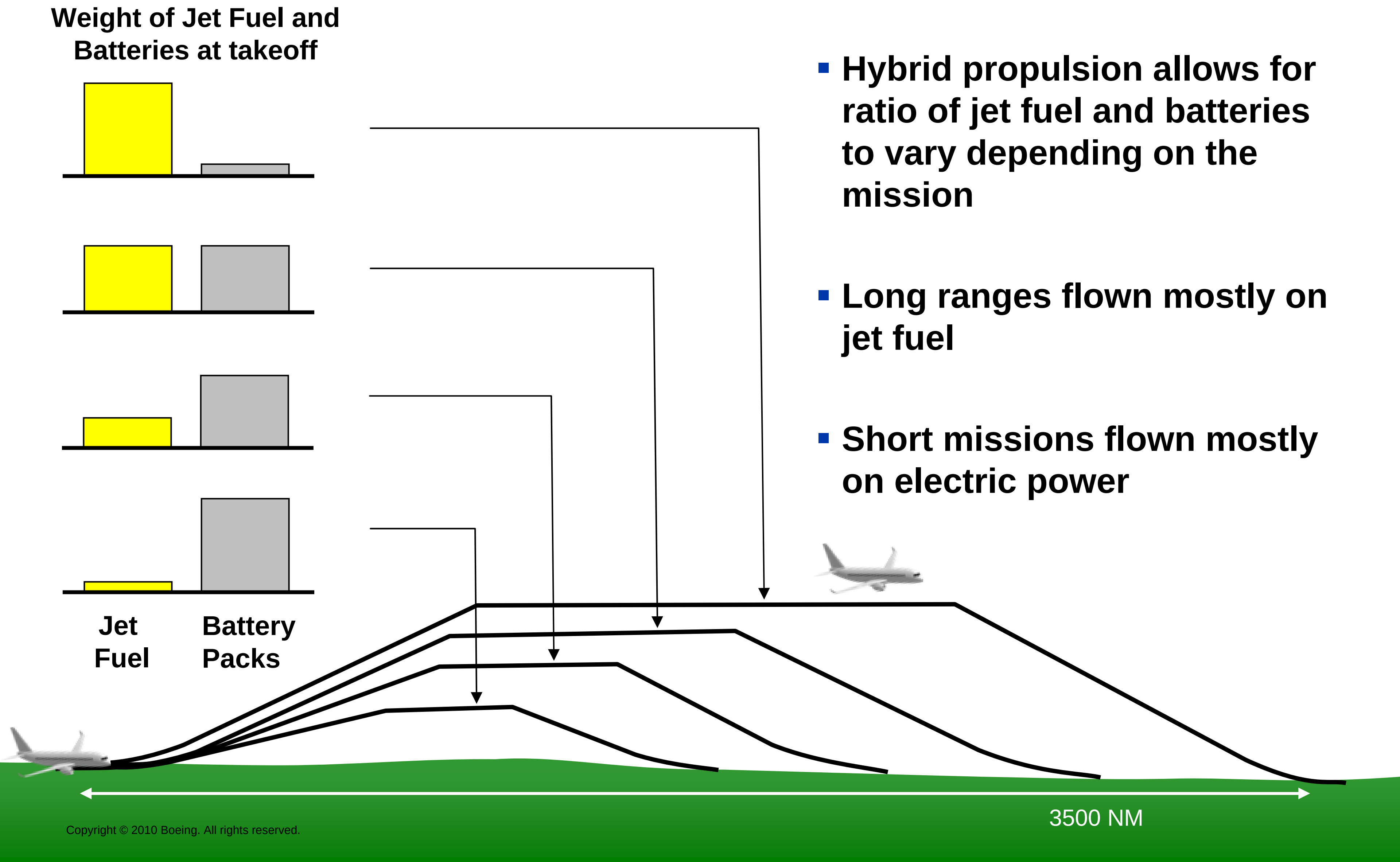
Performance	**Thrust, lbf**	**SFC, lbm/lbf-hr**
SLS (GT mode)	18800	0.211
Rolling tkoff (GT mode)	13385	0.301
Top-of-clmb (hybrid md)	4364	0.372 + 1363 HP in
Cruise (typ. hybrid mode)	3344	0.341 + 1363 HP in

Emissions -72% to -100% relative to CAEP/6

Projected Technologies
Advanced 3-D aero composite fan
Ultra-high PR compressor
Advanced low-emissions combustor
Integrated thrust reverser/variable fan nozzle
Next-gen CMC HPT vanes, blades, and shrouds
Next-gen component aero technology
Next-gen nacelle technology
Improved shaft material
Acoustics technology suite
High DN bearings, high speed/temperature seals
TiAl materials & process technology
Advanced hot section disk material
Active purge control
Advanced CMC blade and vane features
Closed-loop, fast-response turbine ACC
Advanced high efficiency gearbox
High-efficiency lightweight motor controller
Advanced lightweight high efficiency motor
Advanced battery technology (booked w/ airframe techs)
Lightweight, low loss radiators and surface coolers

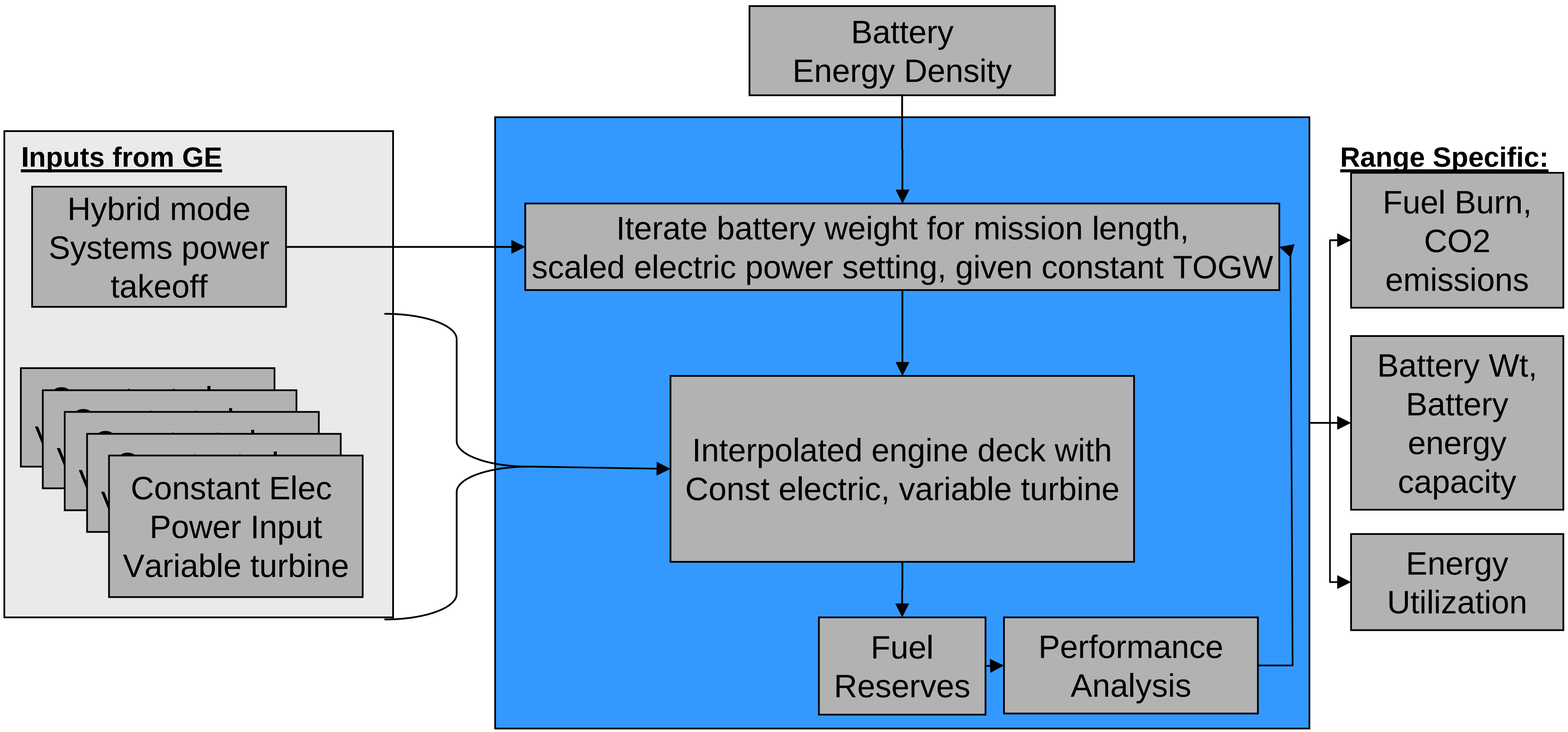
Battery and Jet Fuel Loading

BCA – Advanced Concepts BR&T – Platform Performance Technology



- Hybrid propulsion allows for ratio of jet fuel and batteries to vary depending on the mission
- Long ranges flown mostly on jet fuel
- Short missions flown mostly on electric power

SUGAR Volt - Hybrid Cycle Mission Modeling



SUGAR Volt - Sizing

BCA – Advanced Concepts   BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR Volt

Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

Base SUGAR Volt achieves 63.4% fuel burn reduction

MODEL Sizing Level		SUGAR Free	Refined SUGAR	SUGAR High	SUGAR Volt
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT MAX LANDING WEIGHT MAX ZERO FUEL WEIGHT OPERATING EMPTY WEIGHT FUEL CAPACITY REQ	LB LB LB LB USG	184,800 151,000 142,000 96,000 9,710	139,700 131,800 123,800 77,800 5,512	176,800 167,300 159,300 113,300 5,754	154,900 148,600 140,600 94,600 5,250
ENGINE MODEL FAN DIAMETER BOEING EQUIVLENT THRUST (BET)	 IN LB	Scaled CFM56-7B27 62 28,200	Scaled gFan 66 15,700	Scaled gFan+ 86 19,600	Scaled hFan 80 17,300
WING AREA / SPAN ASPECT RATIO (EFFECTIVE) OPTIMUM CL CRUISE L/D @ OPT CL	FT^2 / FT	1429 / 122 10.41 0.583 18.068	1440 / 129 11.63 0.654 21.981	1722 / 215 26.94 0.828 25.934	1498 / 201 26.94 0.831 24.992
DESIGN MISSION RANGE PERFORMANCE CRUISE MACH LONG RANGE CRUISE MACH (LRC) THRUST ICAC (MTOW, ISA) TIME / DIST (MTOW, 35k FT, ISA) OPTIMUM ALTITUDE (MTOW, ISA) BUFFET ICAC (MTOW, ISA) TOFL (MTOW, SEA LEVEL, 86 DEG F) APPROACH SPEED (MLW)	NMI FT NMI / NMI FT FT FT KT	3,500 0.785 0.785 37,200 23 / 148 35,000 36,200 8,190 126	3,500 0.70 0.70 38,800 29 / 182 38,400 45,200 8,190 115	3,500 0.70 0.70 43,300 29 / 182 42,100 44,000 8,190 115	3,500 0.70 0.70 42,800 29 / 178 42,000 43,900 8,180 116
BLOCK FUEL / SEAT (900 NMI)	LB	92.35 (Base)	51.53 (-44.2%)	56.43 (-38.9%)	33.83 (-63.4%)

PERFORMANCE SUMMARY

SUGAR Volt – Power Trade

* gFan+ engine and no battery systems
** Baseline Volt – No Resizing

200 lb / passenger
Standard Day
Alternate C.G. Performance

*Increasing battery weight reduces fuel burn for the 900 NMI mission***

MODEL Sizing Level		No Electric Systems*	SUGAR Volt 0 lb Battery	1,250 hp 9,150 lb Battery	2,500 hp 16,700 lb Battery	3750 hp 24,250 lb Battery
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	140,100	154,900	154,900	154,900	154,900
MAX LANDING WEIGHT	LB	136,000	148,600	148,600	148,600	148,600
MAX ZERO FUEL WEIGHT	LB	128,000	140,600	140,600	140,600	140,600
OPERATING EMPTY WEIGHT	LB	82,000	94,600	94,600	94,600	94,600
FUEL CAPACITY REQ	USG	4,928	5,250	5,250	5,250	5,250
ENGINE MODEL		Scaled gFan+	Scaled hFan	Scaled hFan	Scaled hFan	Scaled hFan
FAN DIAMETER	IN	78	80	80	80	80
BOEING EQUIVLENT THRUST (BET)	LB	16,200	17,300	17,300	17,300	17,300
WING AREA / SPAN	FT^2 / FT	1292 / 187	1498 / 201	1498 / 201	1498 / 201	1498 / 201
ASPECT RATIO (EFFECTIVE)		26.94	26.94	26.94	26.94	26.94
OPTIMUM CL		0.865	0.831	0.831	0.831	0.831
CRUISE L/D @ OPT CL		24.161	24.992	24.992	24.992	24.992
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70	0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70	0.70	0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	42,900	42,800	42,800	42,800	42,800
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	28 / 181	29 / 178	29 / 178	29 / 178	29 / 178
OPTIMUM ALTITUDE (MTOW, ISA)	FT	41,900	42,000	42,000	42,000	42,000
BUFFET ICAC (MTOW, ISA)	FT	42,900	43,900	43,900	43,900	43,900
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,150	8,180	8,180	8,180	8,180
APPROACH SPEED (MLW)	KT	120	116	116	116	116
TAKEOFF WEIGHT REQUIRED (900 NMI)	LB	123,000	136,500	144,300	151,100	158,000
OPERATING EMPTY WEIGHT (900 NMI)	LB	82,000	94,600	103,750	111,300	118,850
BLOCK FUEL / SEAT (900 NMI)	LB	46.78 (Base)	50.64 (+8.25%)	42.05 (-10.1%)	36.64 (-21.7%)	31.67 (-32.3%)

SUGAR Volt – Electric / Gas Engine Usage

PERFORMANCE SUMMARY

SUGAR Volt – Power Trade

Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		No Electric Systems*	SUGAR Volt 0 lb Battery	1,250 hp 1,800 lb Battery
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	140,100	154,900	152,500
MAX LANDING WEIGHT	LB	136,000	148,600	148,300
MAX ZERO FUEL WEIGHT	LB	128,000	140,600	140,300
OPERATING EMPTY WEIGHT	LB	82,000	94,600	94,300
FUEL CAPACITY REQ	USG	4,928	5,250	4,930
ENGINE MODEL		Scaled gFan+	Scaled hFan	Scaled hFan
FAN DIAMETER	IN	78	80	73
BOEING EQUIVLENT THRUST (BET)	LB	16,200	17,300	14,300
WING AREA / SPAN	FT^2 / FT	1292 / 187	1498 / 201	1592 / 207
ASPECT RATIO (EFFECTIVE)		26.94	26.94	26.94
OPTIMUM CL		0.865	0.831	0.837
CRUISE L/D @ OPT CL		24.161	24.992	25.751
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70	0.70
CLIMB THRUST ICAC (MTOW, ISA)	FT	42,900	42,800	45,200
CRUISE THRUST ICAC (MTOW, ISA)	FT	44,800	44,900	42,600
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	28 / 181	29 / 178	29 / 182
OPTIMUM ALTITUDE (MTOW, ISA)	FT	41,900	42,000	43,700
BUFFET ICAC (MTOW, ISA)	FT	42,900	43,900	45,400
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,150	8,180	8,190
APPROACH SPEED (MLW)	KT	120	116	113
BLOCK FUEL / SEAT (900 NMI)	LB	46.78 (Base)	50.64 (+8.25%)	45.67 (-2.4%)

Hybrid propulsion may allow smaller gas turbine core and achieves fuel burn reduction

* For reference: gFan+ engine and no battery systems

SUGAR Volt Trades – MTOW Increase

BCA – Advanced Concepts   BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR Volt – MTOGW Trade

Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performan

179,000 lb MTOGW achieves 70% fuel burn reduction goal!

MODEL Sizing Level		SUGAR Free	SUGAR Volt	SUGAR VOLT Increase MTOW	SUGAR VOLT Increase MTOW
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	184,800	154,900	163,100	179,700
MAX LANDING WEIGHT	LB	151,000	148,600	152,300	159,600
MAX ZERO FUEL WEIGHT	LB	142,000	140,600	144,300	151,600
OPERATING EMPTY WEIGHT	LB	96,000	94,600	98,300	105,600
FUEL CAPACITY REQ	USG	9,710	5,250	5,948	7,373
ENGINE MODEL		Scaled CFM56-7B27	Scaled hFan	Scaled hFan	Scaled hFan
FAN DIAMETER	IN	62	80	82	86
BOEING EQUIVLENT THRUST (BET)	LB	28,200	17,300	18,000	23,600
WING AREA / SPAN	FT^2 / FT	1429 / 122	1498 / 201	1597 / 207	1769 / 218
ASPECT RATIO (EFFECTIVE)		10.41	26.94	26.94	26.94
OPTIMUM CL		0.583	0.831	0.827	0.826
CRUISE L/D @ OPT CL		18.068	24.992	25.365	25.894
DESIGN MISSION RANGE	NMI	3,500	3,500	4,000	4,900
PERFORMANCE CRUISE MACH		0.785	0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.785	0.70	0.70	0.70
CLIMB THRUST ICAC (MTOW, ISA)	FT	37,200	42,800	42,900	43,100
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	23 / 148	29 / 178	29 / 181	29 / 177
OPTIMUM ALTITUDE (MTOW, ISA)	FT	35,000	42,000	42,200	42,300
BUFFET ICAC (MTOW, ISA)	FT	36,200	43,900	44,200	44,300
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190	8,180	8,190	8,200
APPROACH SPEED (MLW)	KT	126	116	114	111
BATTERIES CARRIED (900 NMI)	LB	0	20,900	25,200	35,500
OPERATING EMPTY WEIGHT (900 NMI)	LB	96,000	116,500	123,500	141,100
BLOCK FUEL / SEAT (900 NMI)	LB	92.35 (Base)	33.83 (-63.4%)	31.54 (-65.8%)	26.23 (-71.6%)

SUGAR Volt – TOFL Trade

PERFORMANCE SUMMARY

SUGAR Volt – TOFL Trade

Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		SUGAR Volt Base	1,250 hp	2,500 hp	3,750 hp
MAX TAKEOFF WEIGHT **BATTERY WEIGHT** **OPERATING EMPTY WEIGHT**	LB LB LB	154,900 0 94,600	154,900 320 94,600	154,900 530 94,600	154,900 740 94,600
ENGINE MODEL **FAN DIAMETER** **BOEING EQUIVLENT THRUST (BET)**	 IN LB	Scaled hFan 80 17,300	Scaled hFan 80 19,400	Scaled hFan 80 21,300	Scaled hFan 80 23,000
DESIGN MISSION RANGE **TOFL (MTOW, SEA LEVEL, 86 DEG F)**	NMI FT	3,500 8,180	3,450 6,800	3,420 6,040	3,385 5,600
TAKEOFF WEIGHT REQUIRED (900 NMI) **TOFL (900 NMI, SEA LEVEL, 86 DEG F)** **BLOCK FUEL / SEAT (900 NMI)**	LB FT LB	136,500 5,980 50.64 (Base)	136,800 5,140 50.71 (+0.1%)	137,000 4,740 50.76 (+0.2%)	137,200 **4,425** 50.81 (+0.3%)

Hybrid propulsion system allows operational flexibility to trade TOFL for cruise efficiency (battery weight)

SUGAR Volt Trades – Open Fan

BCA – Advanced Concepts

BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR Volt – Open Fan Trade

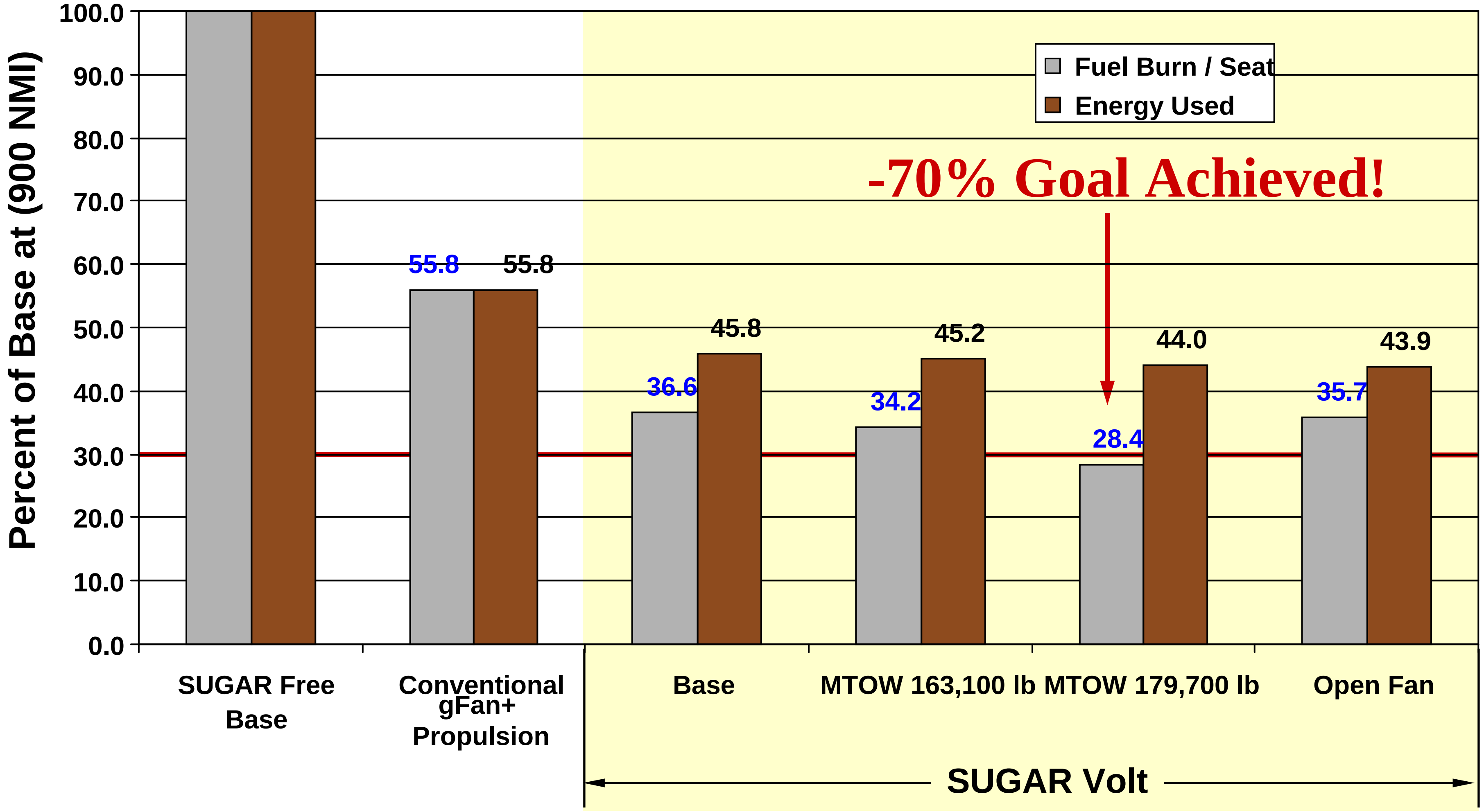
Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		SUGAR Volt	SUGAR Volt Open Fan
PASSENGERS / CLASS		154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	154,900	159,200
MAX LANDING WEIGHT	LB	148,600	155,500
MAX ZERO FUEL WEIGHT	LB	140,600	147,500
OPERATING EMPTY WEIGHT	LB	94,600	101,500
FUEL CAPACITY REQ	USG	5,250	4,854
ENGINE MODEL		Scaled hFan	Scaled hFan Open Fan
FAN DIAMETER	IN	80	~144
BOEING EQUIVLENT THRUST (BET)	LB	17,300	17,600
WING AREA / SPAN	FT^2 / FT	1498 / 201	1558 / 205
ASPECT RATIO (EFFECTIVE)		26.94	26.94
OPTIMUM CL		0.831	0.827
CRUISE L/D @ OPT CL		24.992	25.457
DESIGN MISSION RANGE	NMI	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	42,800	42,900
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	29 / 178	29 / 179
OPTIMUM ALTITUDE (MTOW, ISA)	FT	42,000	42,200
BUFFET ICAC (MTOW, ISA)	FT	43,900	44,100
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,180	8,190
APPROACH SPEED (MLW)	KT	116	117
BLOCK FUEL / SEAT (900 NMI)	LB	33.83 (Base)	32.97 (-2.5%)

Use of open fan results in additional fuel burn reduction

SUGAR Volt Performance Trades Summary



Energy calculated using 750 Whr / Kg battery technology and 18,580 BTU / Lb Fuel

SUGAR Volt - Emissions

- hFan
  - **21%* of CAEP/6 (79% reduction relative to CAEP/6)**
  - **CO_2:** 107 klbs at 900 nmi
  - **CO_2 with biofuel:** 54 klbs at 900 nmi
- hFan with Open Fan
  - **19%** of CAEP/6 (81% reduction relative to CAEP/6)**
  - **CO_2:** 104 klbs at 900 nmi
  - **CO_2 with biofuel:** 52 klbs at 900 nmi

** Assumes 25% thrust from electric motor (emissions not verified by GE)*

*** Assumes additional 11% improvement from open fan (emissions not verified by GE)*

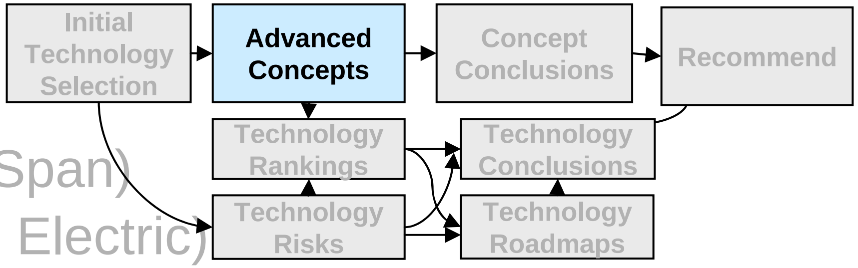
SUGAR Volt Conclusions

- **Variable Battery and Fuel Ratios**
  - Increased design flexibility
  - Increased operational flexibility
  - Increasing TOGW reduces fuel burn *AND* energy utilization
- **Batteries**
  - Battery energy density assumed: 750 Wh/kg
  - Vehicle sizing sensitive to battery technology
  - Significantly reduced energy density required compared to all battery aircraft
- **Emissions / Fuel Burn**
  - ***Flexible hybrid concept can meet or beat NASA fuel burn and emissions goals***
  - Emissions and their environmental impact depend on operational concept
  - "Optimal" configuration depends on value of electricity vs. jet fuel and associated emissions
- **Airport operations will limit realistic vehicle wing spans**
- **Significant Opportunity for Analysis and Optimization**
  - Operation schemes, propulsion & sizing, noise trajectory optimization

SUGAR Phase 1 Final Review

10:05

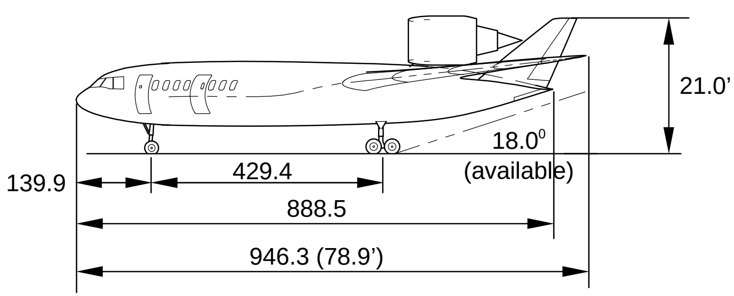
- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- **Concept Performance and Sizing from 12-Month Review**
  - SUGAR Free (N Baseline)
  - Refined SUGAR (N+3 Reference)
  - SUGAR High (N+3 Advanced High Span)
  - SUGAR Volt (N+3 Advanced Hybrid Electric)
  - <u>SUGAR Ray (N+3 Advanced HWB Low Noise)</u>
  - Sized Vehicle Summary & Comparisons

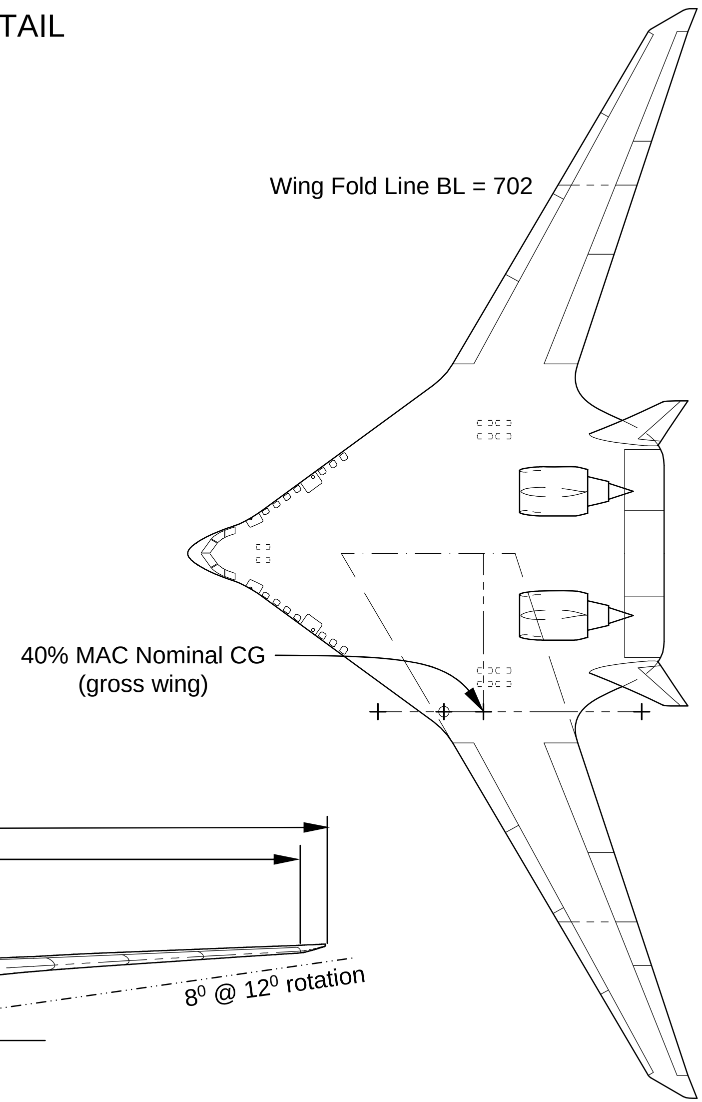


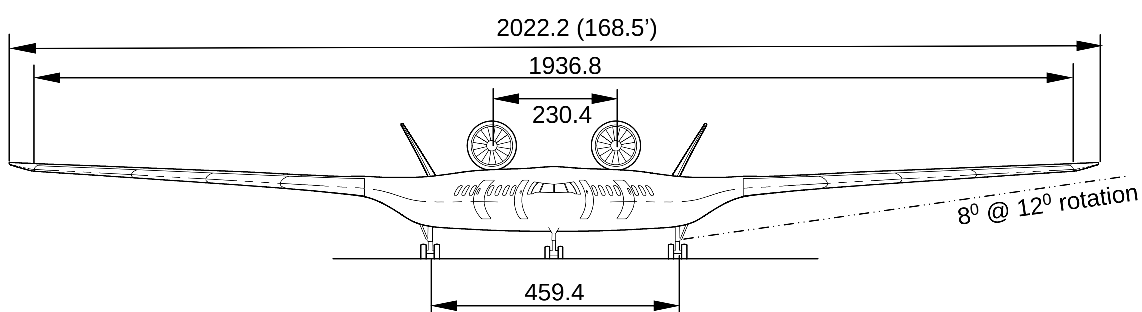
- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- Lunch
- Proprietary Session

SUGAR Ray (765-097) – Three View

	WING	V-TAIL	H-TAIL
Area (gross)	4,136.0	90.8	N/A
Aspect Ratio (gross)	6.865	1.705	
Taper Ratio (trap)	0.228	0.366	
MAC Inches (gross)	489.7	101.3	
Dihedral (Deg.)	3.0	62.0	
1/4 Chord Sweep (Deg.)	27.7	39.2	
Root Chord (Inches) (trap)	322.6	129.23	
Tip Chord (Inches) (trap)	73.6	44.90	
Span (W/O Winglet)	1,936.8		







SUGAR Ray – Technology Description

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

Subsystem Technologies	
Power Management	Adaptive
Power Generation	Eng. Primary; APU Gnd. & Bkup.
APU	Conventional or Diesel
Actuators	EMA
Control Architecture	Maximize Use of Fiberoptics
Thermal Technology	Lightweight
Electro Magnetic Effects / Lightning	More Tolerant Systems & Dual Use Structure
Fuel	Low Sulfur Jet-A, Synthetic or Biofuels
Flight Avionics	NextGen ATM Capable
Wiring	High Conductivity, Lightweight
Computing Networks	Integrated

Aero Technologies	
Laminar Flow	Passive/Natural and Active Where Appropriate
Riblets	Fuselageand Wing Where Appropriate
Excrescence Drag	Multi-Functional Structures, Reduced Fasteners, Reduced Flap Fairings
Empennage	Relaxed Static Stability & Increased C_{LMax}
Airfoil Technology	Supercritical
Additional Technologies	Low Interference Nacelles Airframe Noise Shielding

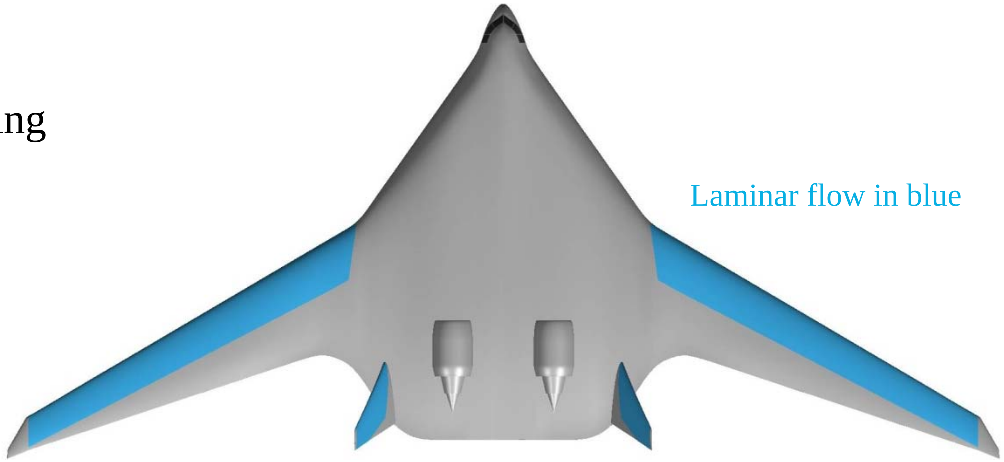
Structural Technologies	
Materials / Manufacturing	Adv. Composites incl. Hybrid Polymer, Adv. Metals, Adv. Joining, Adv. Ceramics
Health Management	On-board Structurally Integrated SHM, Advanced NDE/NDI
Loads & Environments	Maximize Flight Control Integration, Active/Passive Aeroelastic Response for Load Control
Design & Criteria	Reliability Based, Robust/Unitized, Multi-Functional Structures, Support for NLF
Adaptive Structures for Control Systems	Conformal, Gapless, Adaptive, Spanwise Load Control
Energy Management	Structurally Integrated Thermal and Electrical Energy Management
Coatings	Enable Lightweight Materials, Energy Harvesting, Thermal Management, Drag Reduction
Interiors	More Lightweight
Additional Structures Technologies	Lightweight Wing Folds, Adv. Material Forms, Adv. Non-Circular Fuse.

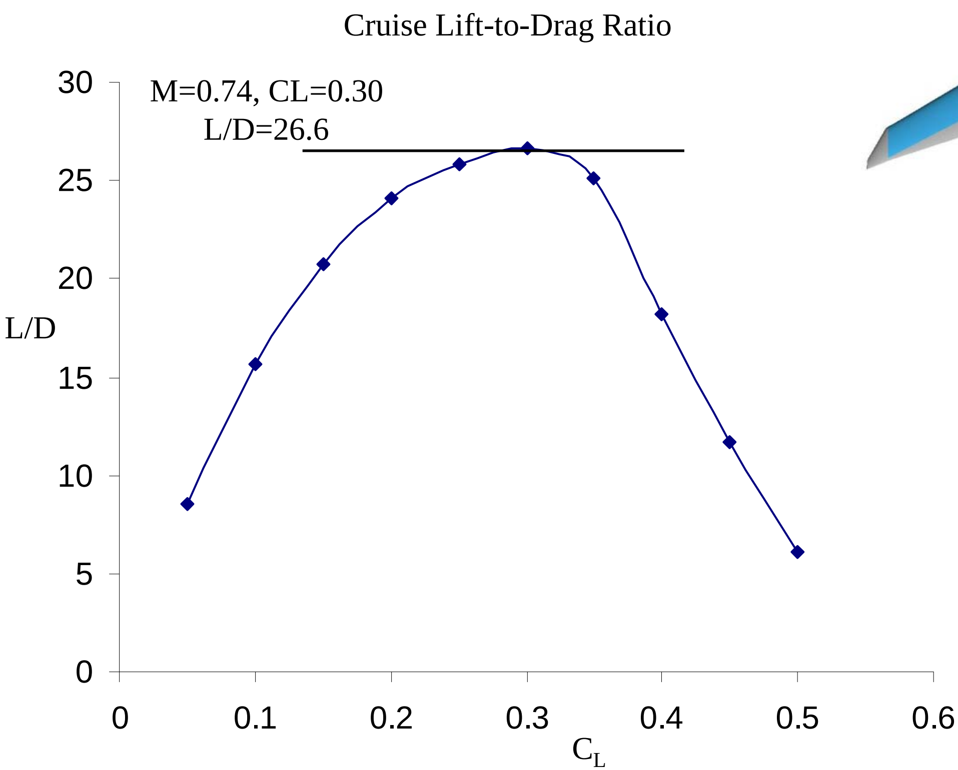
Propulsion Technologies	
Engine Cycle	Very high BPR turbofan with Advanced engine technologies
Combustor	Variable Flow Splits, Ultra-compact low emissions combustor
Materials	Refined SUGAR + MMC's, Advanced CMC mat'ls & processes
Acoustic	Refined SUGAR + Active noise control/fluidics, Non-Ax symmetric nozzles, Unique/shielded installations
Mechanical	Additional advanced systems (as needed)

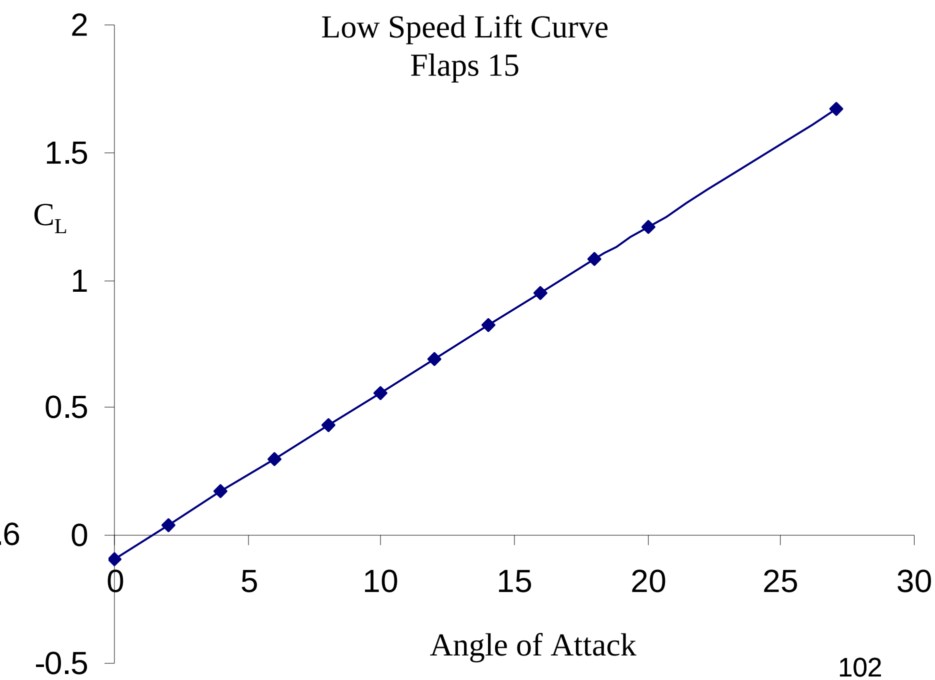
SUGAR Ray - Aero

BCA – Advanced Concepts | BR&T – Platform Performance Technology

- Laminar flow over wing and vertical tails
- Riblets on fuselage and turbulent portion of wing
- Improved excrescence
- Low interference nacelles





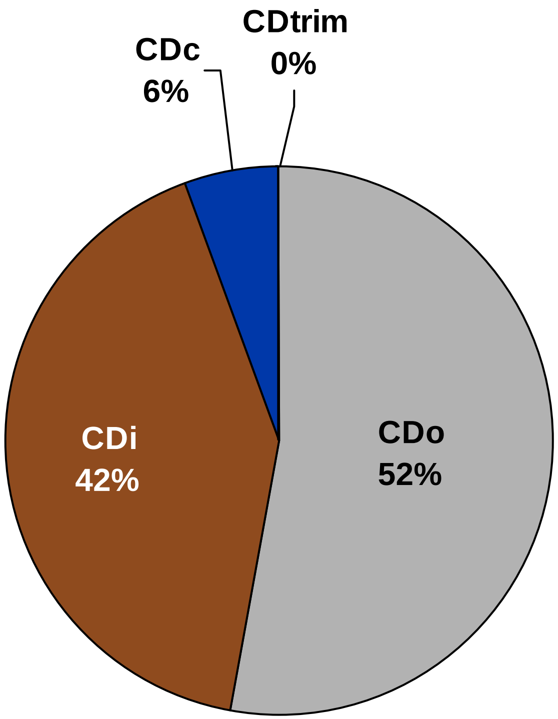


SUGAR Ray – High Speed Aerodynamics

BCA – Advanced Concepts

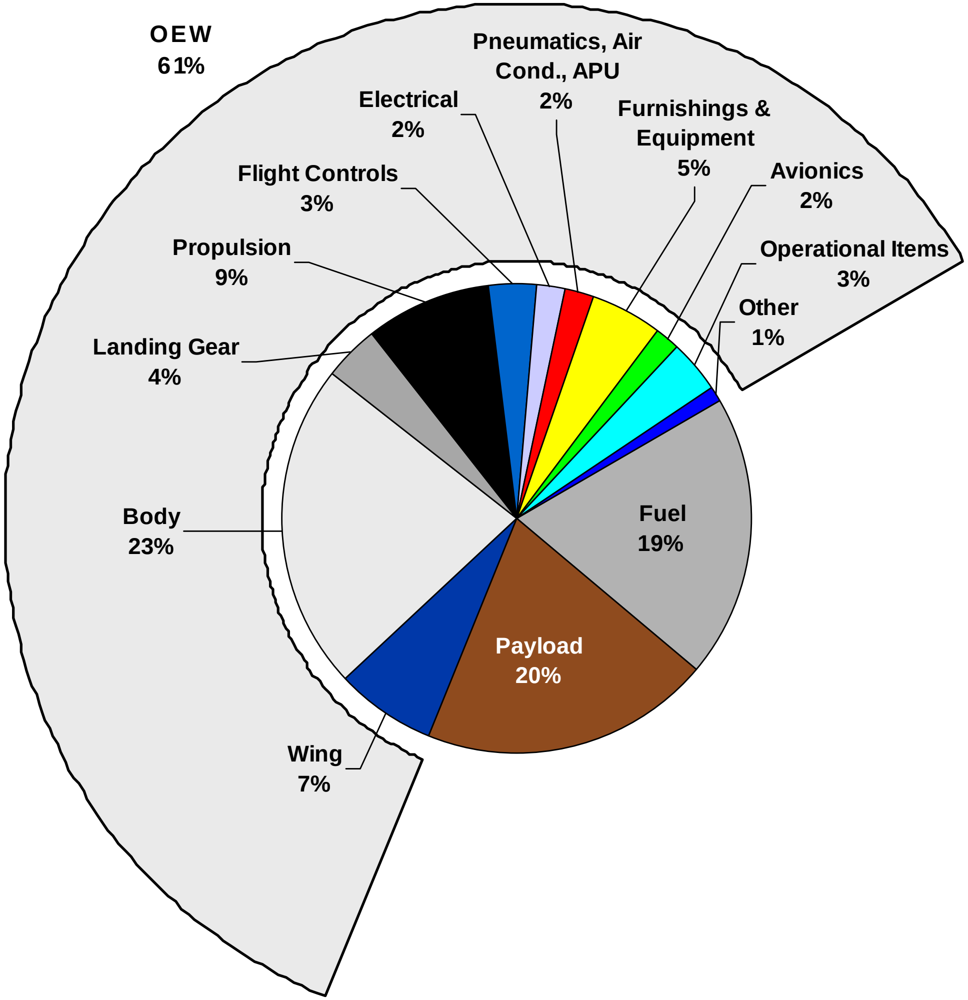
BR&T – Platform Performance Technology

SUGAR Ray	
SREF (FT**2)	5109
FN (LBS)	22022
AR	6.341
M-CRUISE	0.74
SWEEP (DEG)	27.7
T/C-AVE	0.1312
AIRFOIL TYPE	CONVENTIONAL
S-HORIZ (FT**2)	
S-VERT (FT**2)	
F BUILD-UP (FT2)**	
FUSELAGE	0.0000
WING	29.2743
WINGLET	0.2365
HORIZONTAL	0.4800
VERTICAL	0.9025
N&P	2.9900
CANOPY	0.0000
GEAR PODS	0.0000
ETC BEFORE SUB	-5.7256
EXCRESCENCE	2.2808
UPSWEEP	0.0000
WING TWIST	0.0000
STRAKES	0.0000
ETC AFTER SUB	0.0000
FUSELAGE BUMP	0.0000
F-TOTAL (FT2)**	**30.4384**
E-VISC	**0.965**
CRUISE CD BUILD-UP	
M-CRUISE	0.74
CL-CRUISE	0.3
CRUISE ALTITUDE	35000
CD0	0.00596
CDI	0.00468
CDC	0.00063
CDTRIM	
CDTOT	**0.01127**
L/D	**26.611**



SUGAR Ray - Mass Properties

SUGAR RAY WEIGHT BREAKDOWN	BWB SUGAR 155 PA
GROUP	WEIGHT (LB)
WING	12,500
BODY	41,137
VERTICAL TAILS	904
LANDING GEAR	7,198
Engine, Nacelle, and Pylon	14,192
ENGINE SYSTEM	400
FUEL SYSTEM	1,326
FLIGHT CONTROLS & HYDRAULICS	6,015
ELECTRICAL	3,346
PNEUMATICS, AIR CONDITIONING, & APU	3,553
ANTI-ICING	186
FURNISHINGS AND EQUIPMENT	9,080
INSTRUMENTS	1,079
AVIONICS	3,225
MANUFACTURERS EMPTY WEIGHT	104,142
OPERATIONAL ITEMS	6,350
OPERATIONAL EMPTY WEIGHT	110,493
USABLE FUEL	35,582
PAYLOAD	36,425
MAXIMUM TAKEOFF WEIGHT	182,500



SUGAR Ray - Sizing

BCA – Advanced Concepts

BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR Ray

Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

SUGAR Ray fuel burn similar to Refined SUGAR

MODEL Sizing Level		SUGAR Free	Refined SUGAR	SUGAR High	SUGAR Volt	SUGAR Ray
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	184,800	139,700	176,800	154,900	172,600
MAX LANDING WEIGHT	LB	151,000	131,800	167,300	148,600	165,300
MAX ZERO FUEL WEIGHT	LB	142,000	123,800	159,300	140,600	157,300
OPERATING EMPTY WEIGHT	LB	96,000	77,800	113,300	94,600	111,300
FUEL CAPACITY REQ	USG	9,710	5,512	5,754	5,250	5,392
ENGINE MODEL		Scaled CFM56-7B27	Scaled gFan	Scaled gFan+	Scaled hFan	Scaled gFan+
FAN DIAMETER	IN	62	66	86	80	81
BOEING EQUIVLENT THRUST (BET)	LB	28,200	15,700	19,600	17,300	17,500
WING AREA / SPAN	FT^2 / FT	1429 / 122	1440 / 129	1722 / 215	1498 / 201	4139 / 180
ASPECT RATIO (EFFECTIVE)		10.41	11.63	26.94	26.94	26.94
OPTIMUM CL		0.583	0.654	0.828	0.831	0.316
CRUISE L/D @ OPT CL		18.068	21.981	25.934	24.992	27.471
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.785	0.70	0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.785	0.70	0.70	0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	37,200	38,800	43,300	42,800	42,400
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	23 / 148	29 / 182	29 / 182	29 / 178	28 / 180
OPTIMUM ALTITUDE (MTOW, ISA)	FT	35,000	38,400	42,100	42,000	40,800
BUFFET ICAC (MTOW, ISA)	FT	36,200	45,200	44,000	43,900	
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190	8,190	8,190	8,180	7,900
APPROACH SPEED (MLW)	KT	126	115	115	116	103
BLOCK FUEL / SEAT (900 NMI)	LB	92.35 (Base)	51.53 (-44.2%)	56.43 (-38.9%)	33.83 (-63.4%)	52.37 (-43.3%)

SUGAR Ray – OEW Trade

BCA – Advanced Concepts

BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

SUGAR Ray – OEW Trade

Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		-10,000 lb	Cycled for Thrust	+10,000 lb
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	161,500	172,600	184,400
MAX LANDING WEIGHT	LB	155,200	165,300	175,900
MAX ZERO FUEL WEIGHT	LB	147,200	157,300	167,900
OPERATING EMPTY WEIGHT	LB	101,200	111,300	121,900
FUEL CAPACITY REQ	USG	5,232	5,392	5,576
ENGINE MODEL		Scaled gFan+	Scaled gFan+	Scaled gFan+
FAN DIAMETER	IN	82	81	81
BOEING EQUIVLENT THRUST (BET)	LB	18,100	17,500	17,400
WING AREA / SPAN	FT^2 / FT	4139 / 180	4139 / 180	4139 / 180
ASPECT RATIO (EFFECTIVE)		26.94	26.94	26.94
OPTIMUM CL		0.323	0.316	0.313
CRUISE L/D @ OPT CL		26.91	27.471	27.96
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	44,000	42,400	41,200
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	28 / 178	28 / 180	28 / 178
OPTIMUM ALTITUDE (MTOW, ISA)	FT	42,700	40,800	39,200
BUFFET ICAC (MTOW, ISA)	FT			
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	6,700	7,900	9,100
APPROACH SPEED (MLW)	KT	100	103	106
BLOCK FUEL / SEAT (900 NMI)	LB	50.89 (-2.6%)	52.37 (Base)	54.18 (+3.7%)

Sensitivity to OEW has been calculated

SUGAR Ray - Emissions

- gFan+
  - **28% of CAEP/6 (72% reduction relative to CAEP/6)**
  - **CO_2:** 165 klbs at 900 nmi
  - **CO_2 with biofuel:** 83 klbs at 900 nmi

NASA Subsonic Fixed Wing Noise Goals

SUGAR

CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2030-2035 EIS) Advanced Aircraft Concepts (relative to user defined reference)
Noise (cum. below Stage 4)	-32 dB	-42 dB	55 LDN at average airport boundary
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%	-40%	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex concepts

Selection of Airport for Noise Analysis

Decision: Develop a generic airport for noise analysis

Approach:

1. Airport modeled after Cleveland Hopkins International
2. Use detailed Cleveland noise data for method calibration

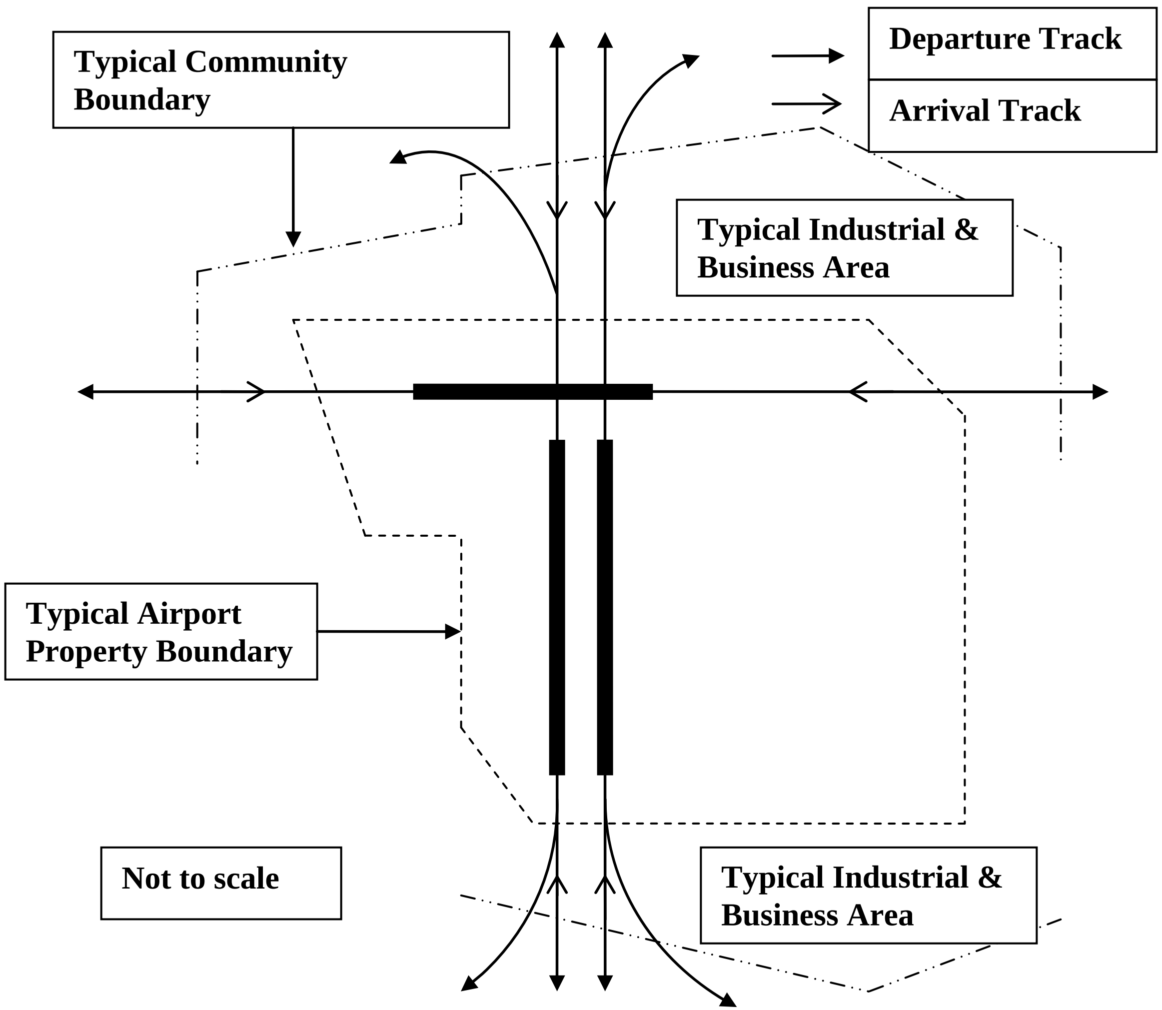
Reasons for using a generic airport:

1. Avoid possible public controversy that could develop if a specific airport is used
2. Increase analysis flexibility to define airport scenarios

Average Hub Airport Layout

BCA – Advanced Concepts

BR&T – Platform Performance Technology



Airport Noise Exposure Forecasts

- Calibrate baseline public domain Airport NEM data (from Part 150 Airport Noise Compatibility program) using FAA INM tool
- Parametrically vary NEM levels and compute DNL contours
- Develop NEM's for N+1, N+2, and N+3 aircraft classes
- Using the Future Scenario, determine number of aircraft operation per class types for 2030 & 2055
- Calculate DNL contours for 2008, 2030, & 2055
- Look at higher substitution of N+3 aircraft and recalculate DNL contours

Noise Methods Calibrated to Airport Data

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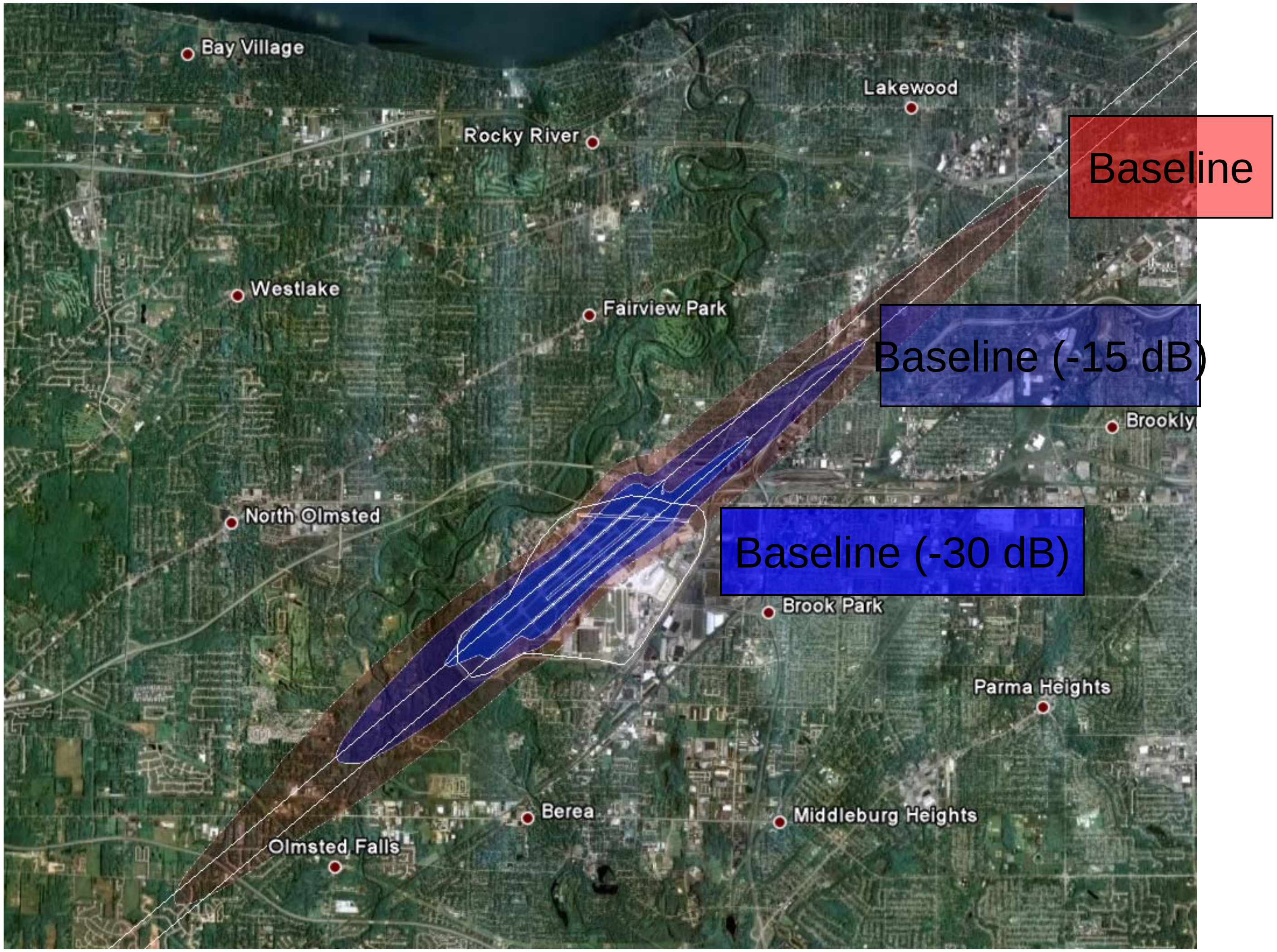


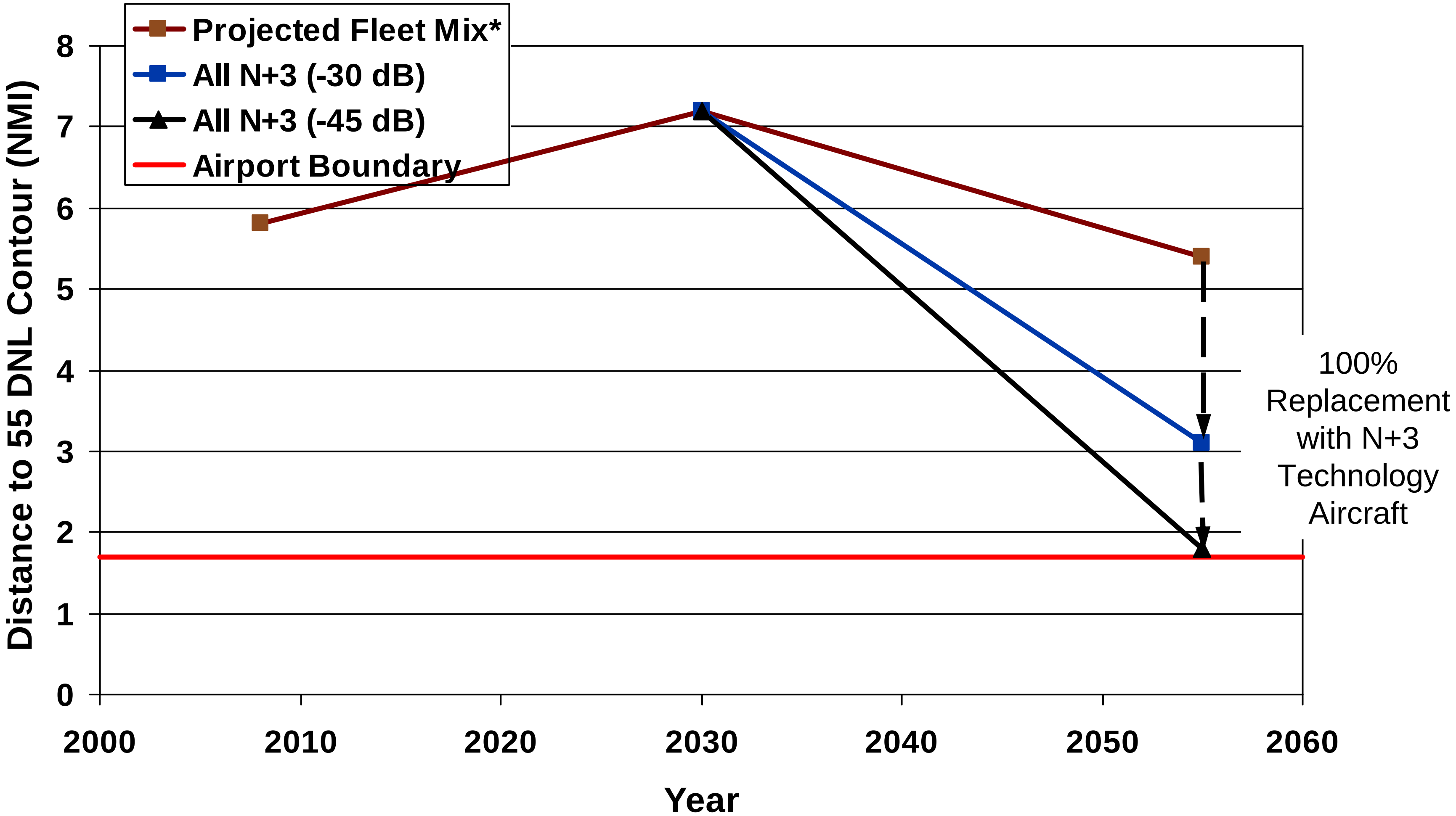
Noise Results for Reference Case and 9 Scenarios

MODEL Sizing Level	55 DNL (MI^2)	55 DNL SW Extent (NMI)	55 DNL NE Extent (NMI)
2008 CALIBRATION (7 A/C)	8.6	4.8	5.1
2008 GENERIC (FORECAST FLEET MIX) (No N+3)	9.3	5.8	5.8
2030 GENERIC (FORECAST FLEET MIX) (N+3 =N -30 dB)	14.2	7.2	7.1
2055 GENERIC (FORECAST FLEET MIX) (N+3 =N -30 dB)	10.2	5.4	5.3
2008 GENERIC (N+3 ONLY) (N+3 = N -30 dB)	1.8	2.0	1.8
2030 GENERIC (N+3 ONLY) (N+3 = N -30 dB)	2.5	2.4	2.2
2055 GENERIC (N+3 ONLY) (N+3 = N -30 dB)	3.6	3.1	2.9
2008 GENERIC (N+3 ONLY) (N+3 = N -45 dB)	0.8	1.2	0.9
2030 GENERIC (N+3 ONLY) (N+3 = N -45 dB)	1.0	1.4	1.2
2055 GENERIC (N+3 ONLY) (N+3 = N -45 dB)	1.4	1.8	1.6
AIRPORT BOUNDARY	~3.5	1.7	1.0

Increasing Operations

-45 dB relative to today's aircraft is required to meet NASA goal assuming ~1.7 Nmi airport boundary and an all N+3 fleet in 2055

What is Required to Meet NASA Goal?



* Fleet Growth and Mixed Technology Fleet

SUGAR Ray Noise & Acoustic Technologies

Configuration	SUGAR Free	SUGAR Ray
Propulsion	CFM-56	gFan+
Relative Noise	0 db	-37 db

- *Boeing Analysis using GE estimates*
- *Some tech interactions are uncertain*

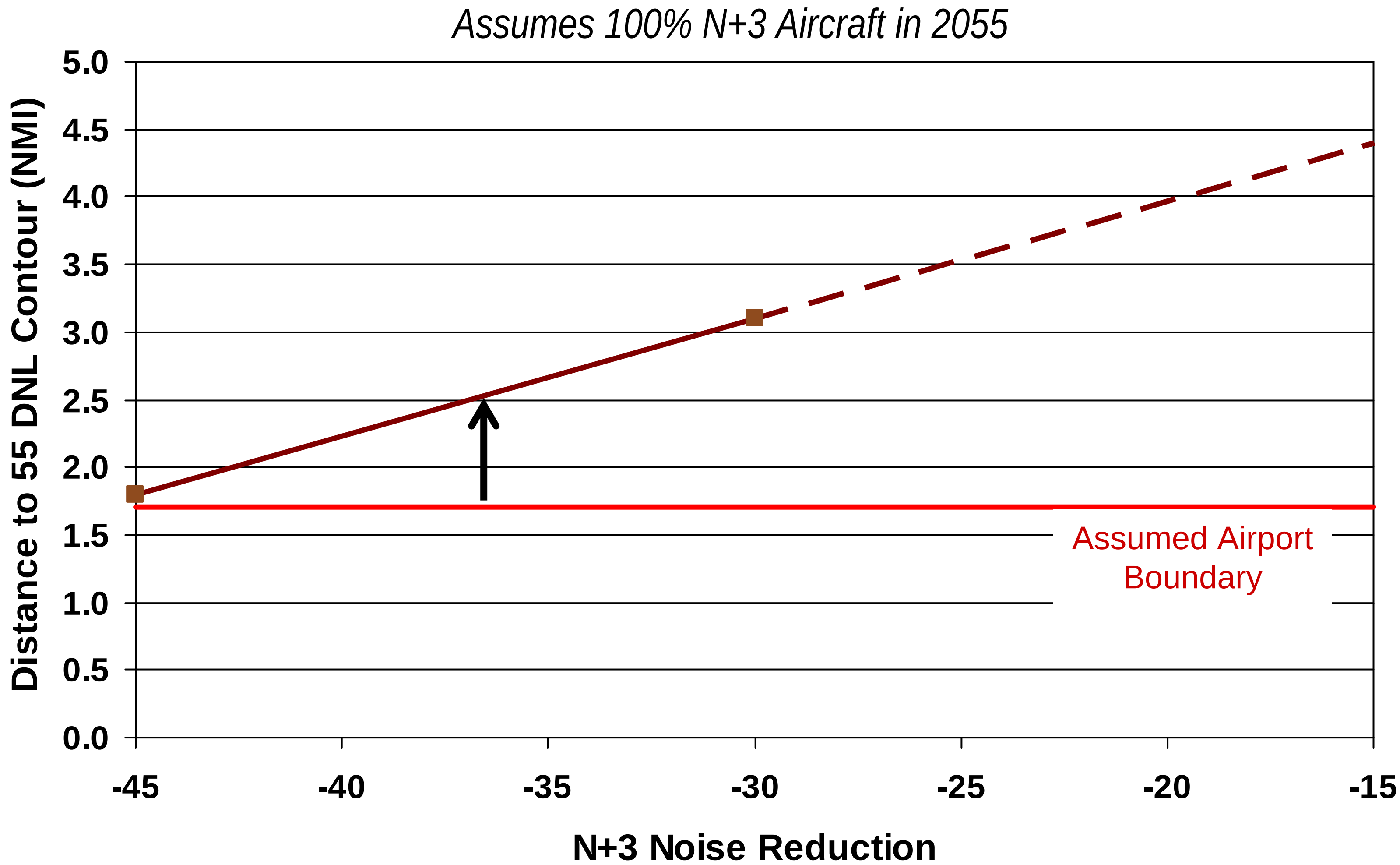
Engine Acoustic Technologies:

- Passive noise absorbers
  - Bulk absorber materials
  - 2DOF and tailored absorbers
- Adv. Passive noise suppression
  - Adv. inlet/cold section treatments
  - Adv. Core & fan nozzle treatments
  - Inlet lip treatments
  - Improved design methods, tailored cutoff
  - Advanced blade & OGV optimization
- Aggressive/active noise suppression
  - Unconventional UHB installations
  - Nonaxisymmetric shapes/inserts
  - Fluidics & flow control
  - Low noise combustor
  - Shape memory alloy components
- Methods improvements

Airframe Acoustic Technologies:

- Airframe weight reduction from structures/materials & systems – reduces TOFL & engine size
- Low speed high lift devices to reduce thrust required for cutback flyover and approach conditions
- Inlet noise shielding from top of wing mounted engines
- Rear jet and exhaust fan duct noise shielding from rear deck/platform for flyover and approach noise reduction and twin verticals for lateral noise reduction and exhaust nozzle designs for distributed jet noise source reduction from shielding
- Airframe noise reduction methods including wing plan-form (airfoil design), main gear fairings, lift & control surface treatments (sealing etc)
- Rear fan duct noise treatment methods

Sensitivity of 55 DNL Distance to N+3 Noise Reduction



N+3 @ -37 dB would require airport boundary at ~2.5 Nmi to meet NASA goal

Recommended Noise Analysis

- **Determine technologies needed for further reduction of N+3 SUGAR Ray noise**

- **Recommended future steps:**
  - Look at other N+3 aircraft and options
    - Open fan
    - Optimum electric usage for SUGAR Volt
    - Detailed flyout and throttle usage

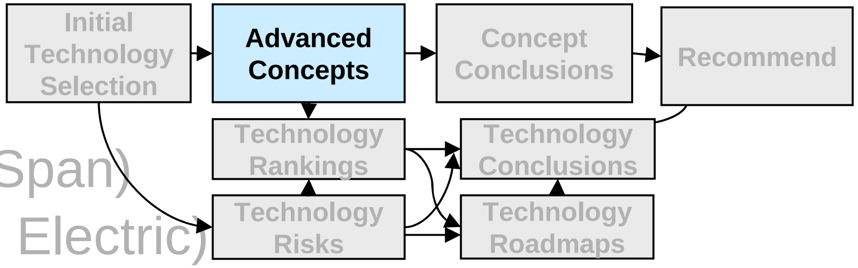
SUGAR Ray Feature Conclusions

- **Configuration issues that need consideration**
  - Emergency egress with collapsed gear
  - Emergency egress for water landing
  - Crash loads due to little space below floor
- **Center body provides significant noise shielding**
- **Additional noise optimization possible**
  - SUGAR has not looked at flight path tailoring for low noise
  - Use of Hybrid Electric propulsion on SUGAR Ray

SUGAR Phase 1 Final Review

10:30

- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- **Concept Performance and Sizing from 12-Month Review**
  - SUGAR Free (N Baseline)
  - Refined SUGAR (N+3 Reference)
  - SUGAR High (N+3 Advanced High Span)
  - SUGAR Volt (N+3 Advanced Hybrid Electric)
  - SUGAR Ray (N+3 Advanced HWB Low Noise)
  - Sized Vehicle Summary & Comparisons



- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- Lunch
- Proprietary Session

Sized Vehicle Summary

MODEL Sizing Level		SUGAR Free	Refined SUGAR gFan	Refined SUGAR gFan+	SUGAR High	SUGAR Volt hFan	SUGAR Ray
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT **MAX LANDING WEIGHT** **MAX ZERO FUEL WEIGHT** **OPERATING EMPTY WEIGHT** **FUEL CAPACITY REQ**	LB LB LB LB USG	184,800 151,000 142,000 96,000 9,710	139,700 131,800 123,800 77,800 5,512	139,500 133,600 125,600 79,600 5,208	176,800 167,300 159,300 113,300 5,754	154,900 148,600 140,600 94,600 5,250	172,600 165,300 157,300 111,300 5,392
ENGINE MODEL **FAN DIAMETER** **BOEING EQUIVLENT THRUST (BET)**	 IN LB	Scaled CFM56-7B27 62 28,200	Scaled gFan 66 15,700	Scaled gFan+ 76 15,300	Scaled gFan+ 86 19,600	Scaled hFan 80 17,300	Scaled gFan+ 81 17,500
WING AREA / SPAN **ASPECT RATIO (EFFECTIVE)** **OPTIMUM CL** **CRUISE L/D @ OPT CL**	FT^2 / FT	1429 / 122 10.41 0.583 18.068	1440 / 129 11.63 0.654 21.981	1407 / 128 11.63 0.708 21.428	1722 / 215 26.94 0.828 25.934	1498 / 201 26.94 0.831 24.992	4139 / 180 26.94 0.316 27.471
DESIGN MISSION RANGE **PERFORMANCE CRUISE MACH** **LONG RANGE CRUISE MACH (LRC)** **THRUST ICAC (MTOW, ISA)** **TIME / DIST (MTOW, 35k FT, ISA)** **OPTIMUM ALTITUDE (MTOW, ISA)** **BUFFET ICAC (MTOW, ISA)** **TOFL (MTOW, SEA LEVEL, 86 DEG F)** **APPROACH SPEED (MLW)**	NMI FT NMI / NMI FT FT FT KT	3,500 0.785 0.785 37,200 23 / 148 35,000 36,200 8,190 126	3,500 0.70 0.70 38,800 29 / 182 38,400 45,200 8,190 115	3,500 0.70 0.70 40,100 29 / 186 39,600 44,800 8,190 117	3,500 0.70 0.70 43,300 29 / 182 42,100 44,000 8,190 115	3,500 0.70 0.70 42,800 29 / 178 42,000 43,900 8,180 116	3,500 0.70 0.70 42,400 28 / 180 40,800 7,900 103
BLOCK FUEL / SEAT (900 NMI)	LB	92.35 (Base)	51.53 (-44.2%)	48.31 (-47.7%)	56.43 (-38.9%)	33.83 (-63.4%)	52.37 (-43.3%)
NOISE **EMISSIONS (NOX)** **EMISSIONS (CO_2) (900 NMI, JET A)**	 CAEP/6 LB	 79.2% 291 (Base)	 41.7% 162 (-44.2%)	 28.0% 152 (-47.7%)	 28.0% 178 (-38.9%)	 21.0% 107 (-63.4%)	 28.0% 148 (-43.3%)

Note: Base airplanes selected for summary
Some trade studies yielded better performance

Configuration Challenges Identified

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Category	SUGAR Free	Refined SUGAR	SUGAR High	SUGAR Volt	SUGAR Ray
Safety & Certification	Would not meet future certification constraints		Thrown Open fan Blade; Ditching Evacuation		Lack of Lower Deck Crush Structure; Ditching Evacuation; Collapsed Gear Evacuation
Airport Compatibility			High Span Wings @ TO and Landing; Vehicle Height around Active Runways		
Additional Concerns			Uncertainty in Wing Weight	Battery Malfunction and Crash Fire Potential	
Opportunities		Significant opportunity for low risk fuel burn reduction	Wing and aero optimization and improvements	Operational Flexibility (Fuel burn, TOFL, noise improvements possible)	Significant noise shielding; planform optimization

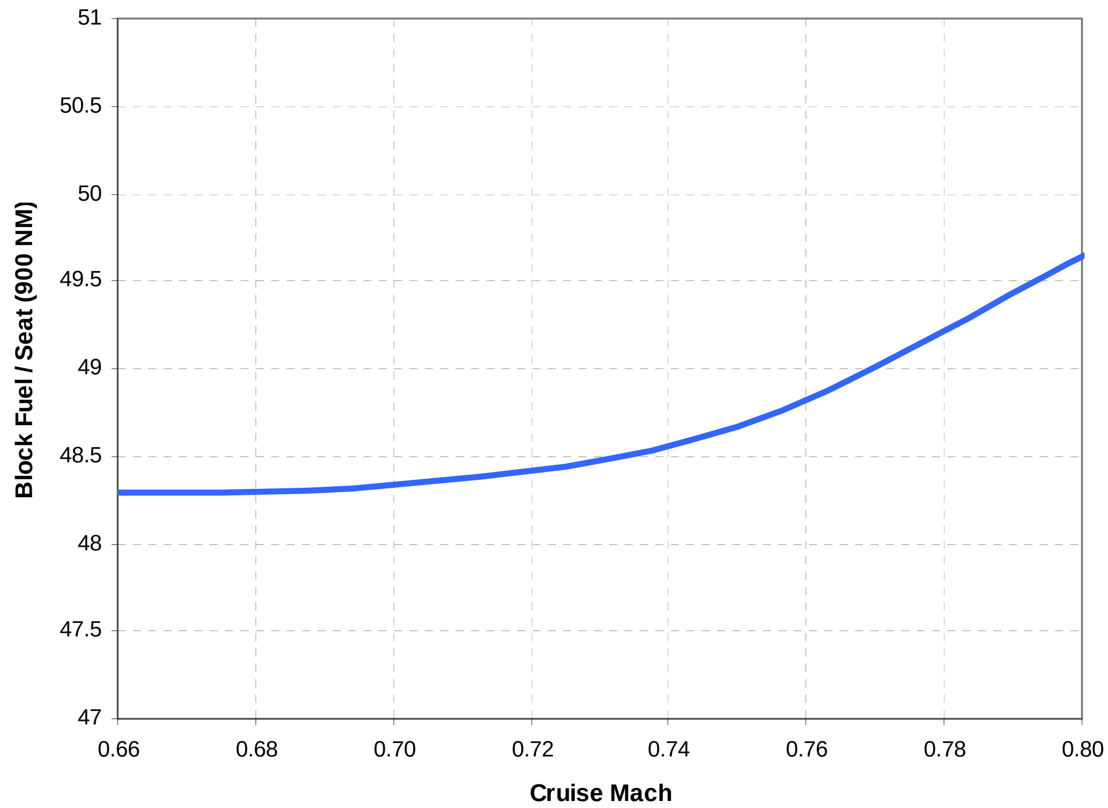
Opportunities Trades

- **The following opportunities trades were performed with the initial sizing analysis methods (same as used in the point of departure study) re-calibrated to the point design data.**

Refined SUGAR – Trades

- If there is a span constraint, cruise speed (between 0.60 and 0.74) is not a significant driver on fuel burn

- Optimized vehicle for cruise speed
  - Same engine thermal efficiency



Refined SUGAR – Opportunities

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- **If cruise altitude is restricted to 27,000-ft**

	Refined SUGAR Gfan+ Engine	Refined SUGAR Gfan+ Engine
Cruise Altitude (MTOW, ISA)	39,600	27,000
Max Takeoff Weight (lbs)	139,500	141,000
Wing Area (ft^2)	1407	1240
Aspect Ratio (Effective)	11.63	13.5
Wing Span (effective)	128	128
Performance Cruise Mach	0.70	0.672
Performance Cruise Knots	402	402
Block Fuel / Seat (900 NMI)	48.31	51.4 (+6.4%)

- **6.4% increase in fuel burn for a resized Refined SUGAR**
- **Additional concerns due to weather avoidance at reduced altitude**
- **Laminar flow and lower cruise speed reduces the penalty of higher dynamic pressure compared to existing airliners.**

Similar result to the 10% increase in fuel burn for a 737-800 (Mark Guynn, TBW Workshop)

Refined SUGAR / Super Refined SUGAR – Opportunities

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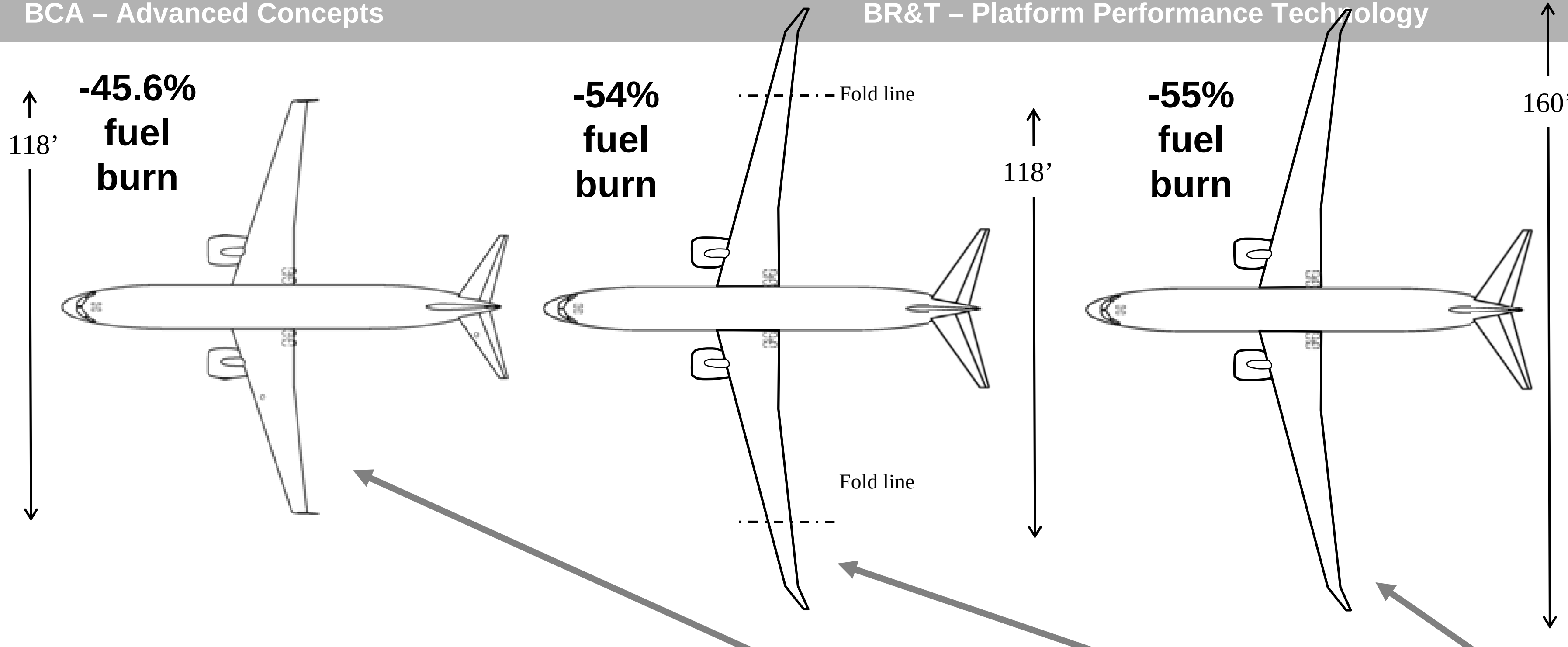
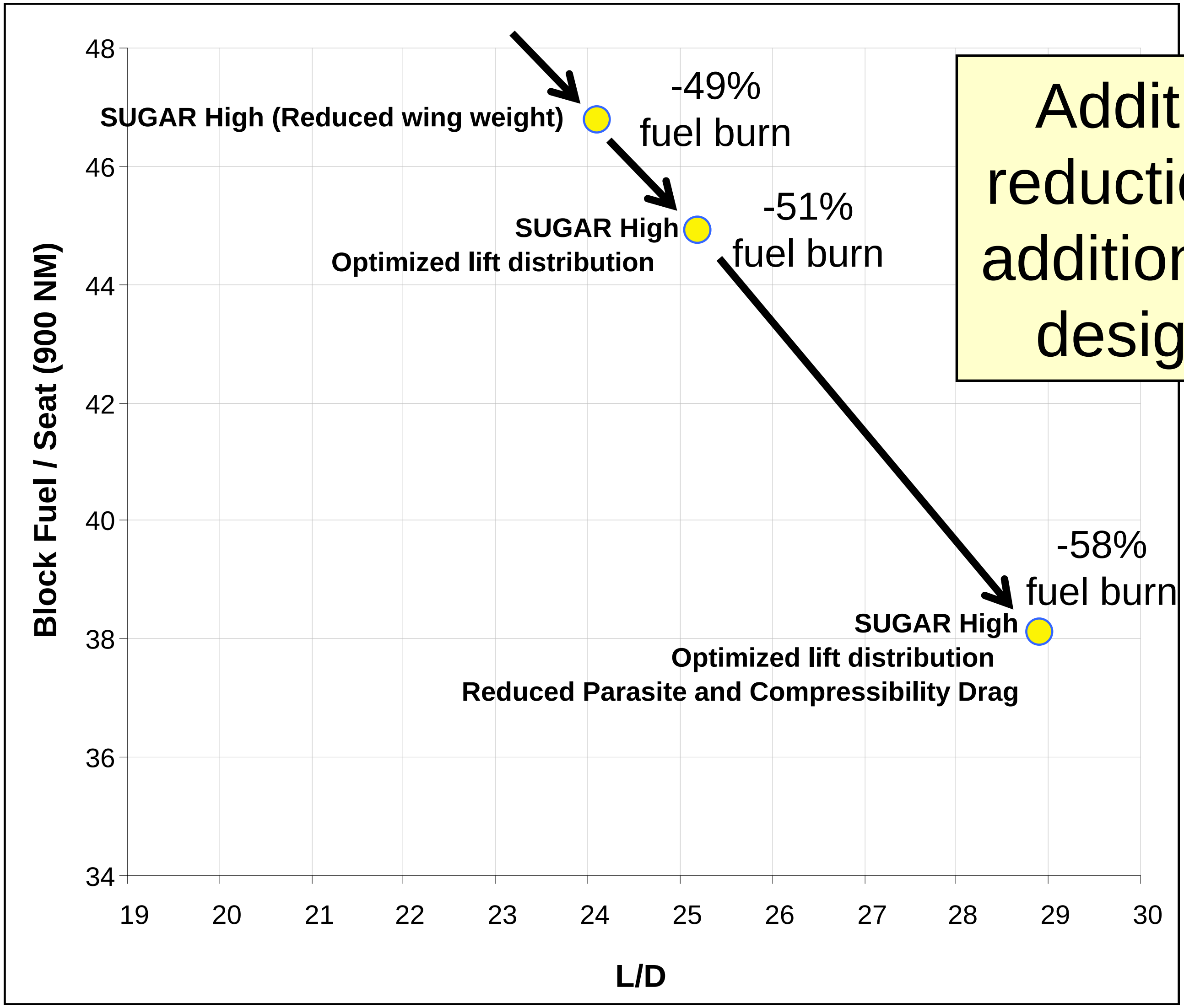


MODEL Sizing Level		Refined SUGAR gFan	Refined SUGAR gFan+	Refined SUGAR gFan+ Span 118 ft	Refined SUGAR gFan+ Span 118 ft SUGAR High Aero	Refined SUGAR gFan+ No Span Constraint SUGAR High Aero Fold Wt	Refined SUGAR gFan+ No Span Constraint SUGAR High Aero 2 x Fold Wt	Refined SUGAR gFan+ No Span Constraint SUGAR High Aero No Fold
CRUISE ALTITUDE (MTOW, ISA)	ft	38,400	39,600	39,600	39,600	41,500	41,500	41,500
MAX TAKE OFF WEIGHT	Lb	139,700	139,500	139,400	139,500	141,905	143,336	140,100
WING AREA	ft^2	1,440	1,407	1,407	1,407	1,600	1,600	1,600
ASPECT RATIO (EFFECTIVE)		11.63	11.63	11.63	11.63	16.0	16.0	16.0
WING SPAN (TRUE)	ft	129	128	118	118	160	160	160
CRUISE L/D		21.98	21.4	20.4	21.6	24.8	24.8	25.33
CRUISE MACH NUMBER		0.70	0.70	0.70	0.70	0.70	0.70	0.70
FUEL BURN / SEAT (900 NMI)	lb	51.3	48.31	50.19	47.0	42.50	42.92	41.57

“Super Refined SUGAR”

SUGAR High – Opportunities



Additional fuel burn reduction possible with additional aerodynamic design optimization

SUGAR Volt Trades – Battery Technology

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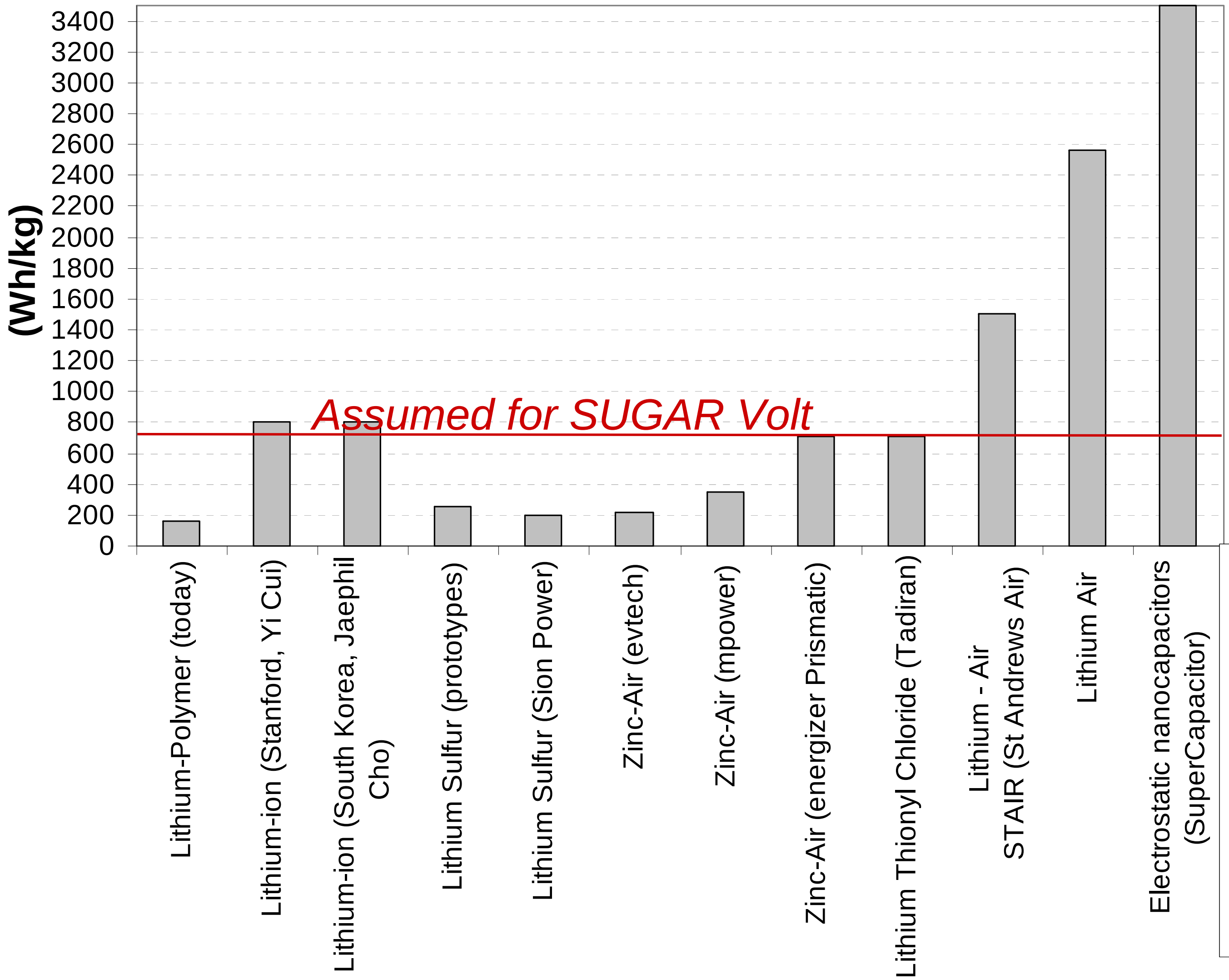
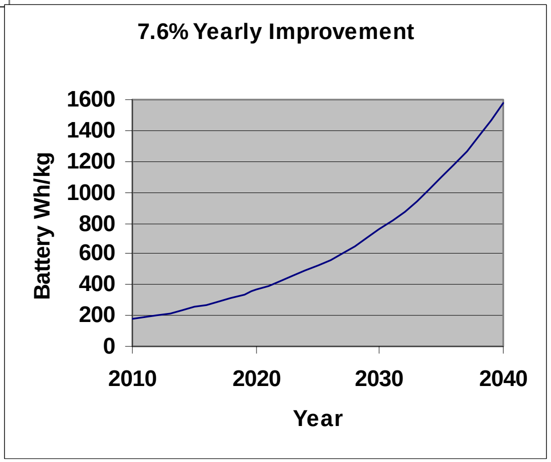
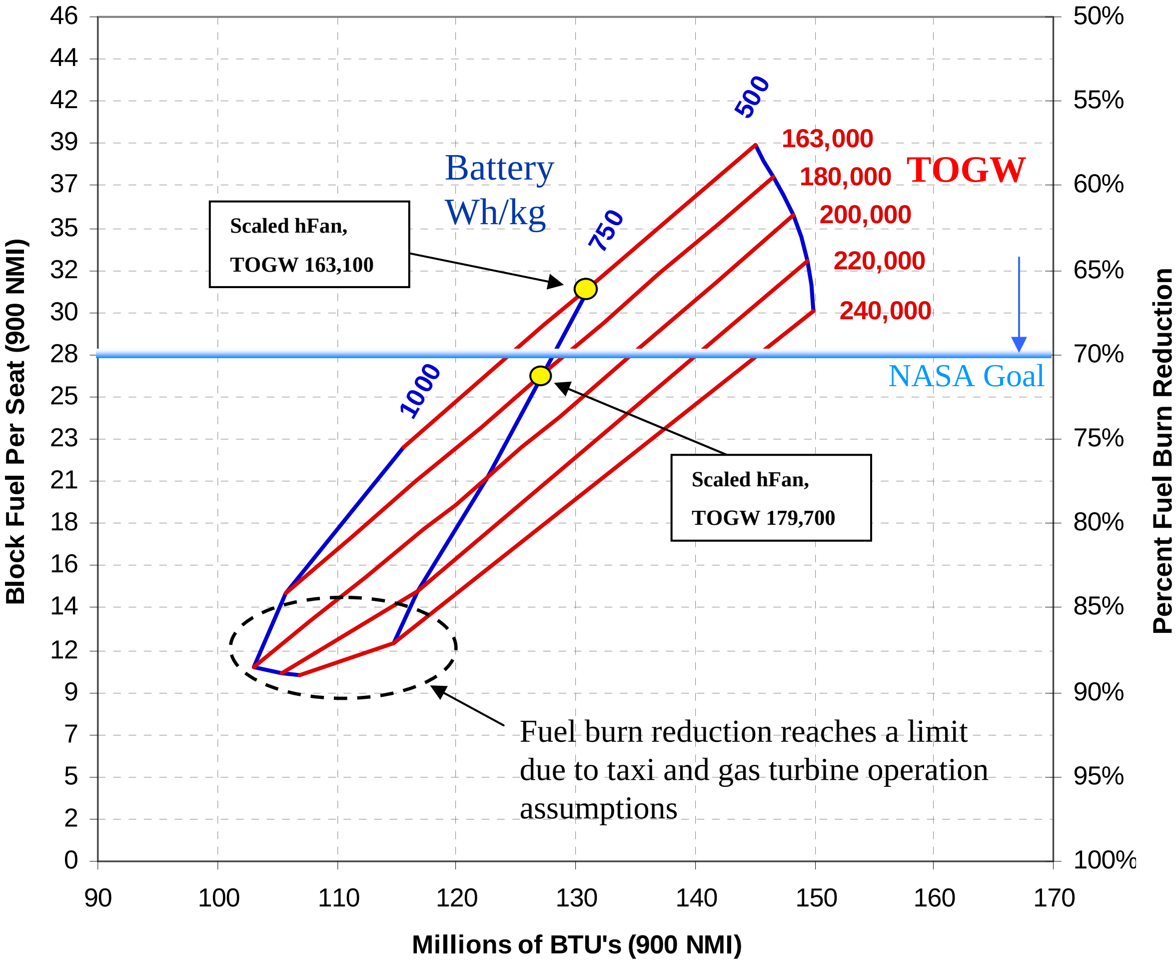


- **Battery performance is very important to achieving fuel burn reduction**
- **750 Wh/kg selected for SUGAR Volt**
- **7.6% Yearly improvement needed to reach 750 Wh/kg by 2030**

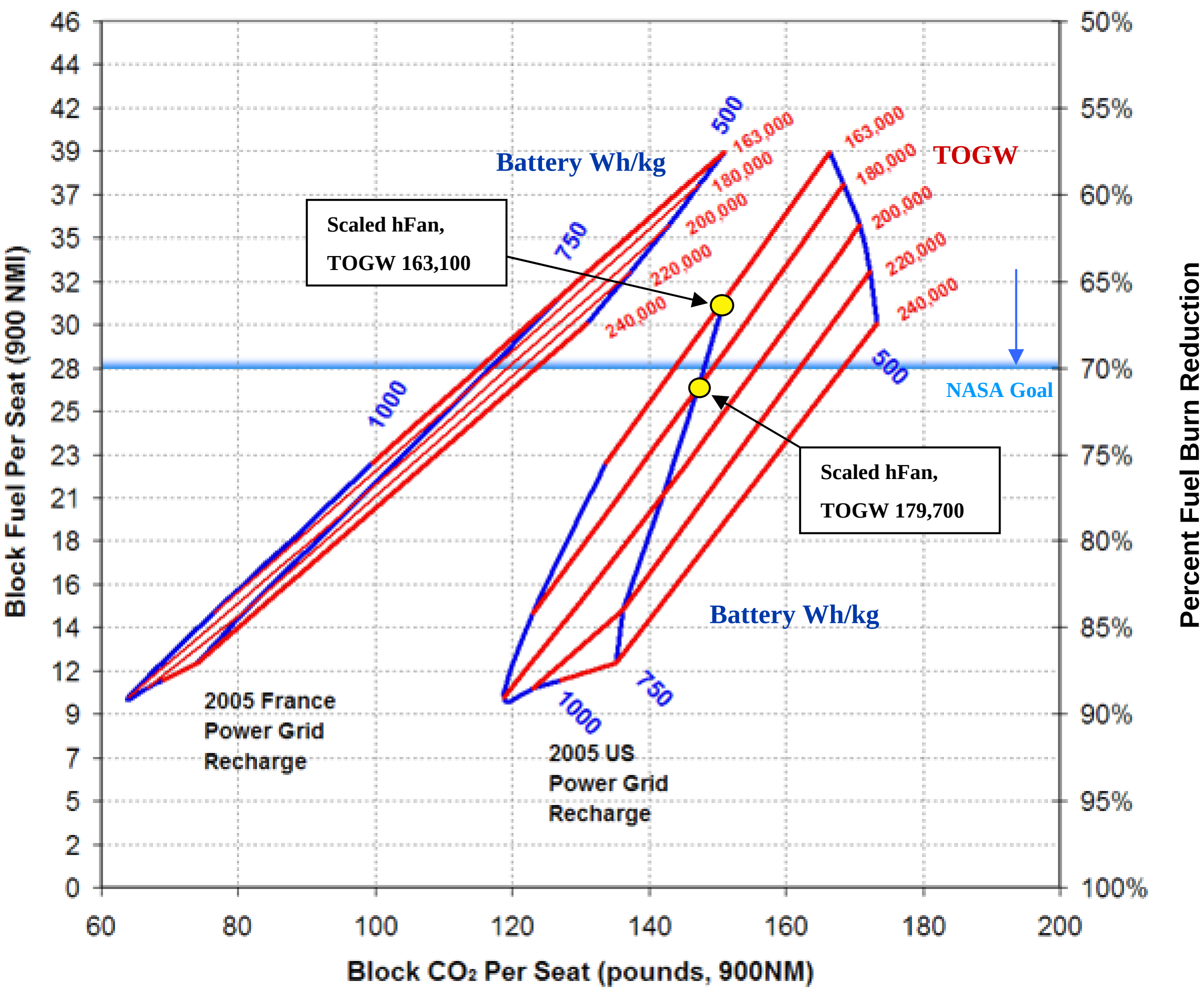


SUGAR Volt – Opportunities



- With a 750 Wh/kg battery, increasing aircraft weight to accommodate higher battery capacity reduces fuel burn and total energy
- >500 WH/kg battery technology needed to meet NASA fuel burn goal
- 85-90% fuel burn reduction is max. achievable for SUGAR hybrid architecture and assumptions

SUGAR Volt – Opportunities

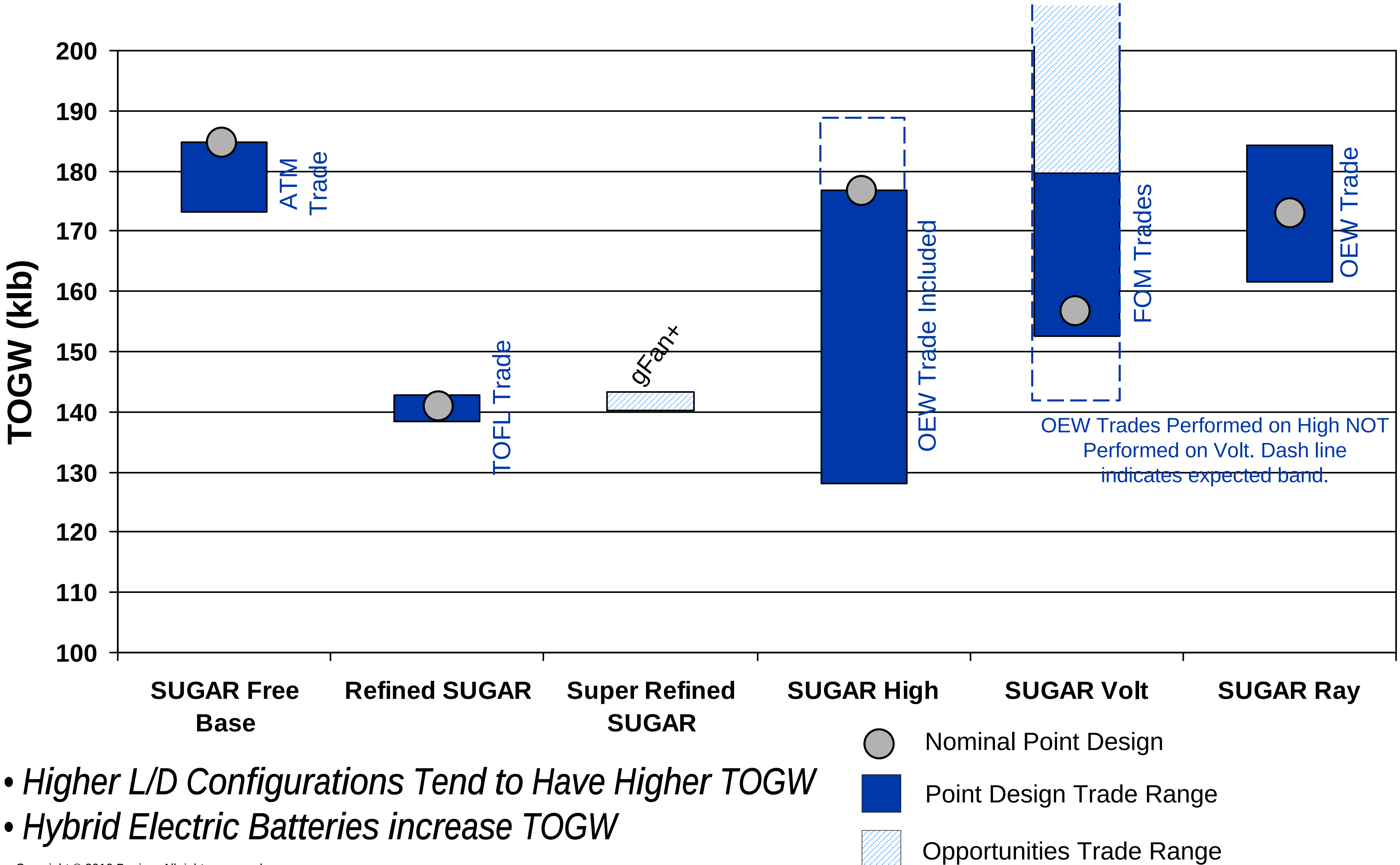


- The energy source for battery recharging has a big impact on CO_2.
- Recharging from the US grid results in smaller CO_2 reduction from increased TOGW's than alternate sources of power
- Volt potential increases if US grid is improved by the 2035 timeframe

SUGAR Ray - Opportunities

- **Additional planform optimization and weight reduction potential**
- **Add open fan for reduced fuel burn**
- **Add hybrid electric propulsion for fuel burn, emissions, and noise benefits**

Comparisons – TOGW



- *Higher L/D Configurations Tend to Have Higher TOGW*
- *Hybrid Electric Batteries increase TOGW*

Comparisons – Empty Weight

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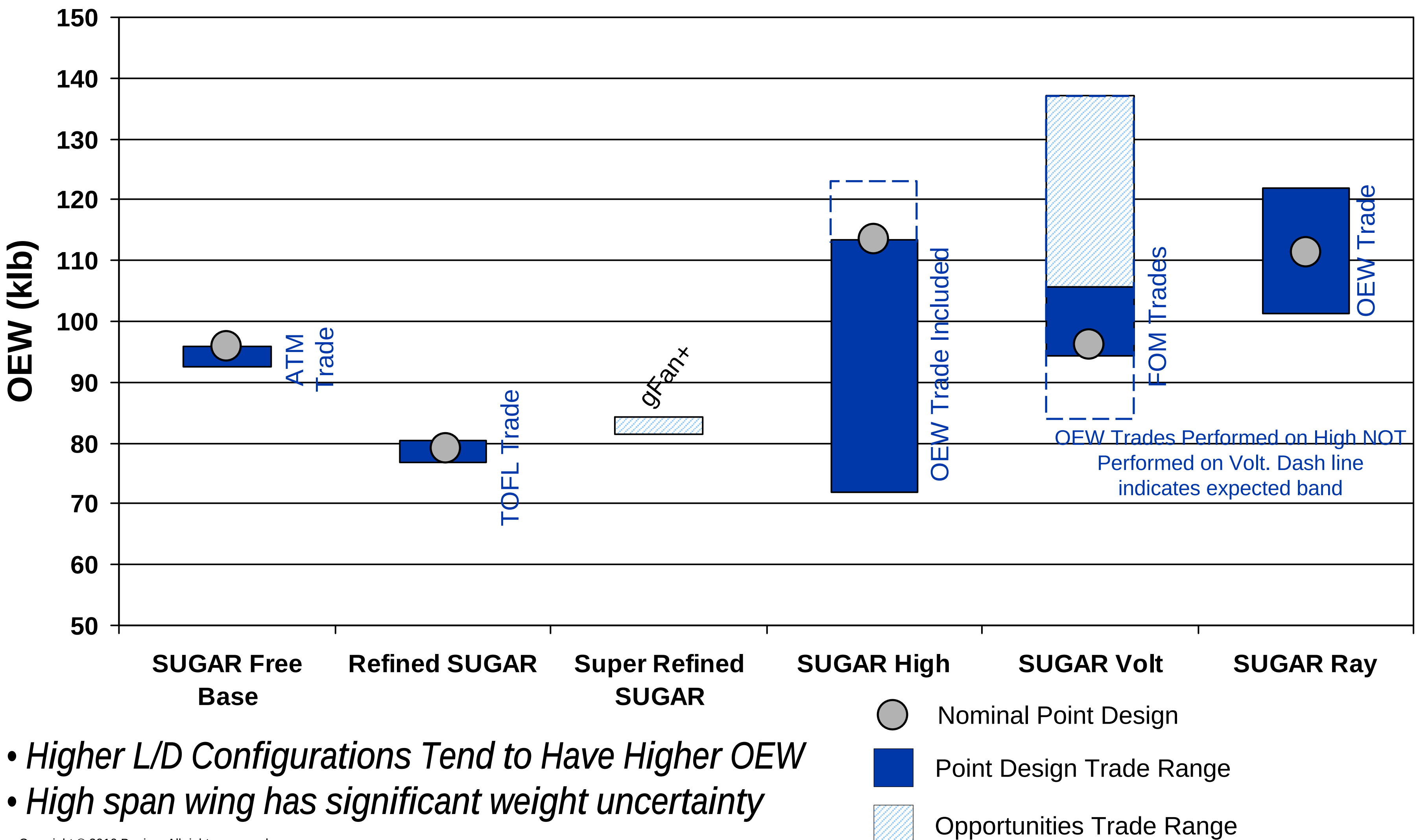
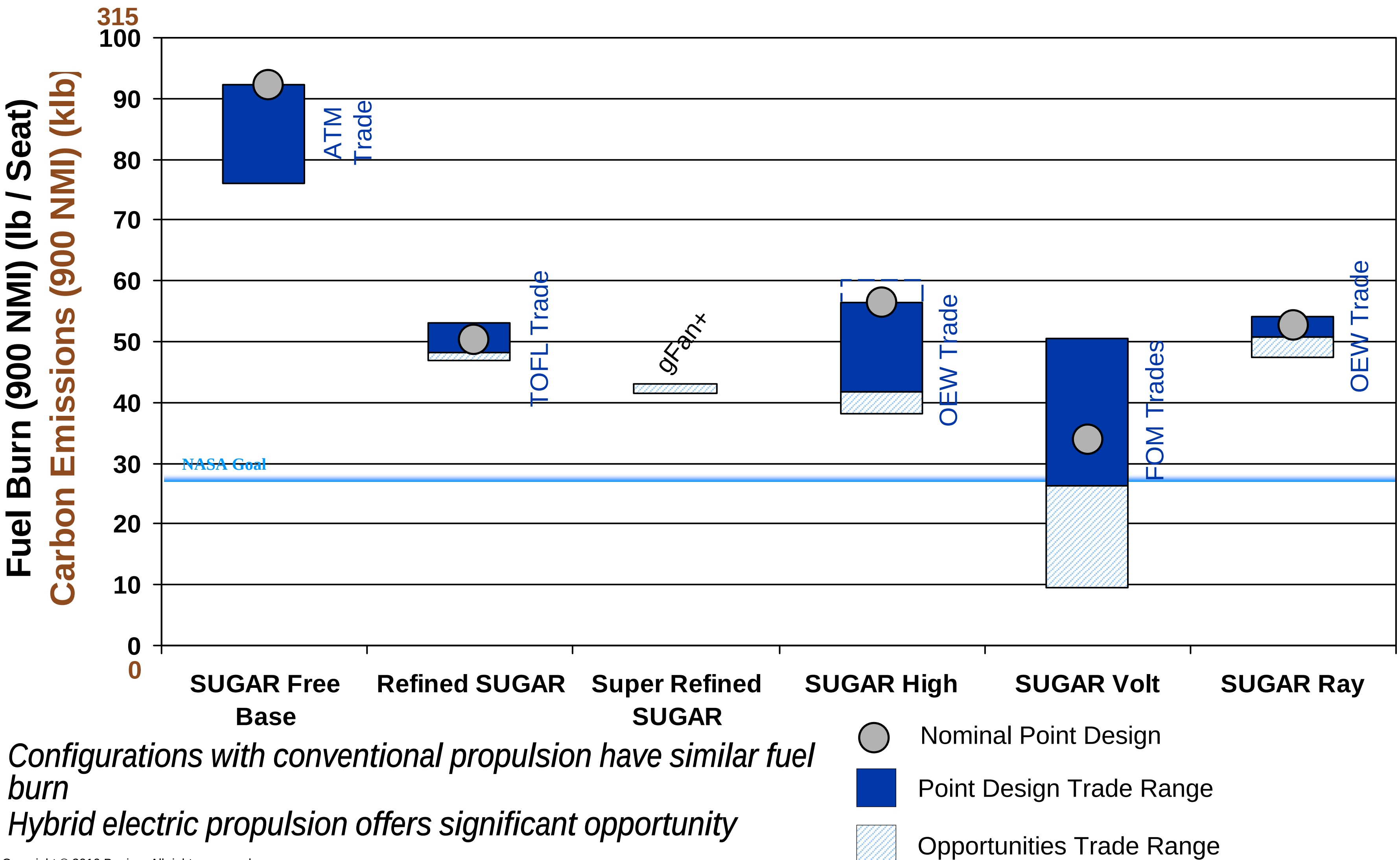


- *Higher L/D Configurations Tend to Have Higher OEW*
- *High span wing has significant weight uncertainty*

Comparisons – Fuel Burn and CO_2 Emissions



- *Configurations with conventional propulsion have similar fuel burn*
- *Hybrid electric propulsion offers significant opportunity*

Fuel Burn Reduction for Various Ranges

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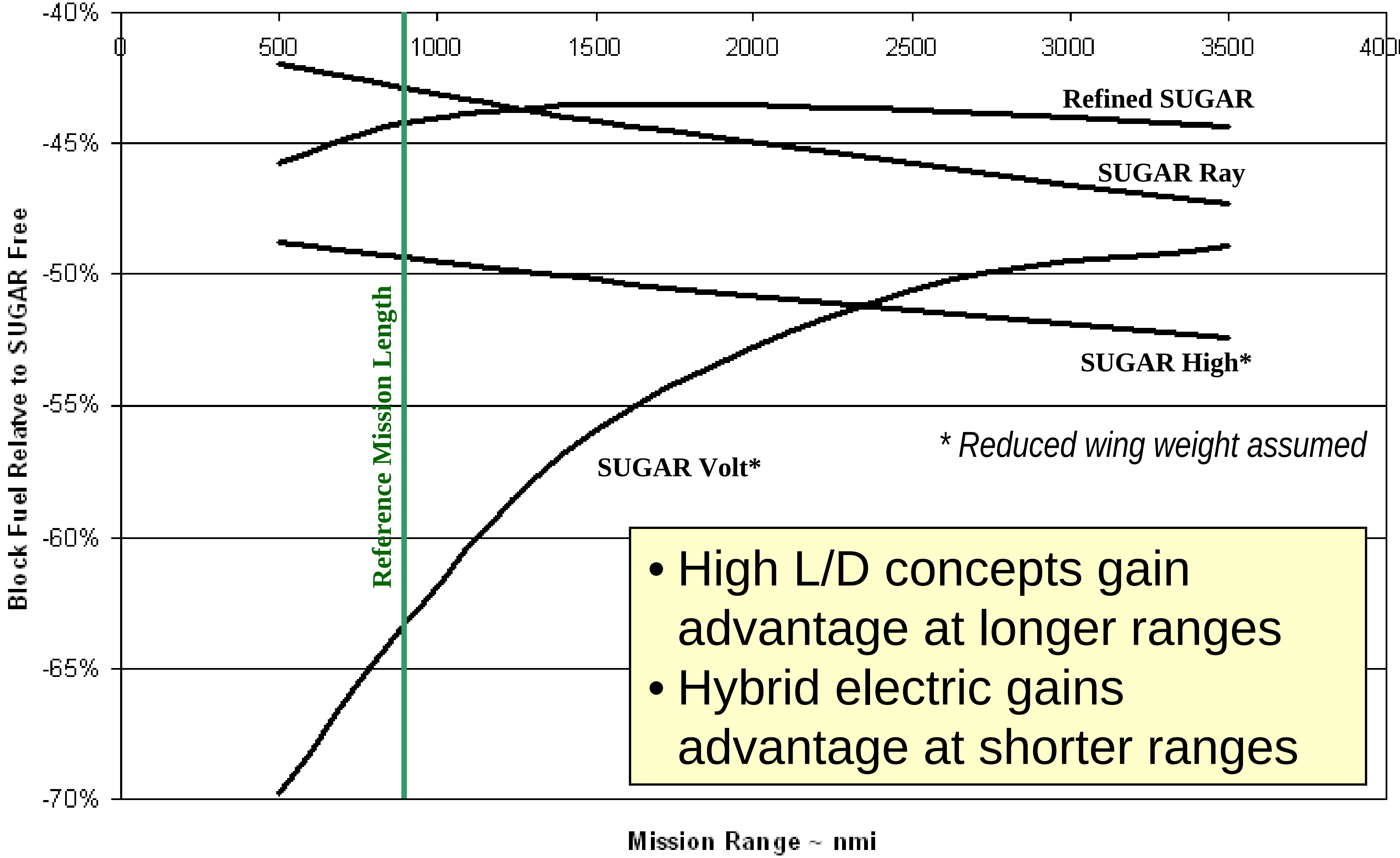
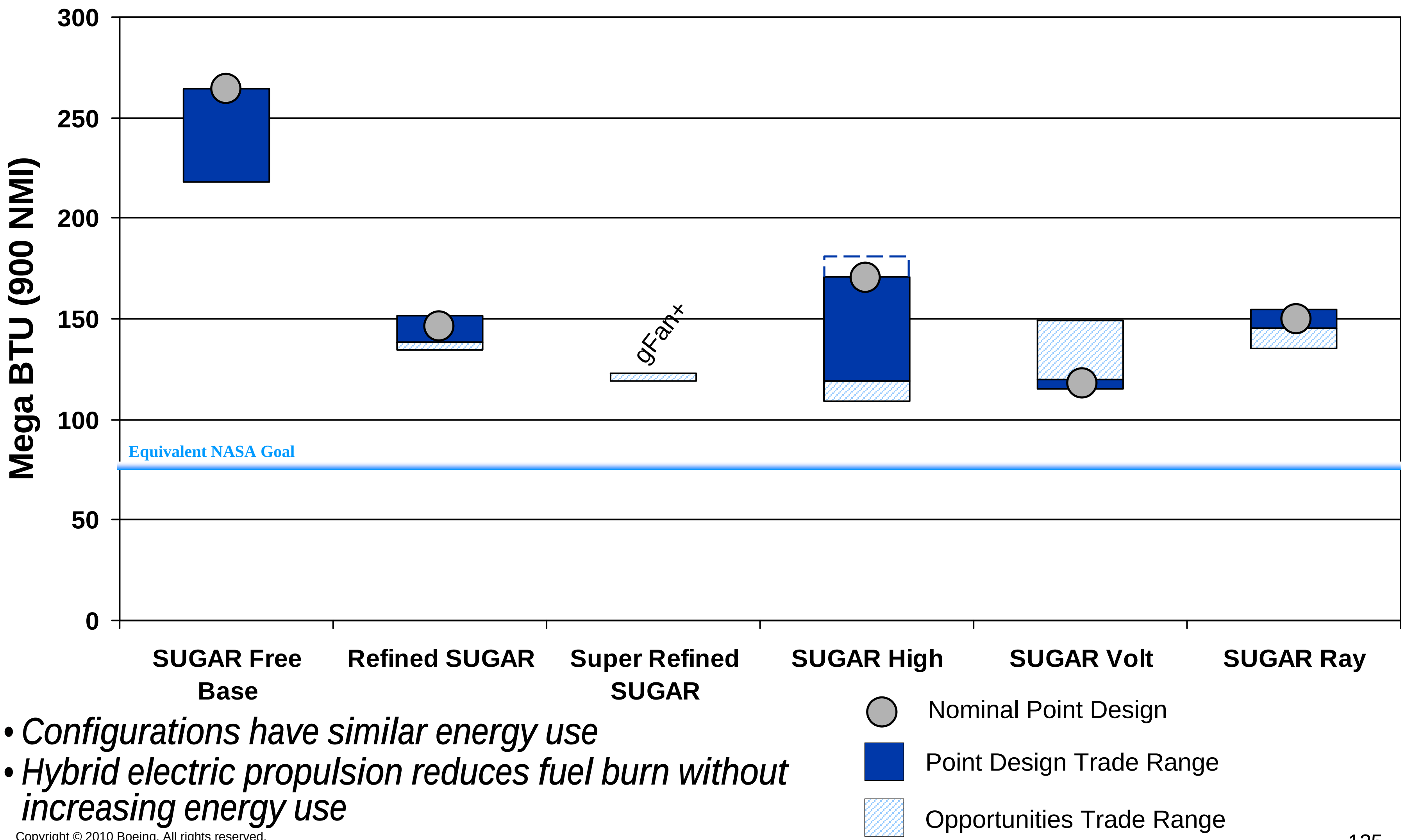


- High L/D concepts gain advantage at longer ranges
- Hybrid electric gains advantage at shorter ranges

Comparisons – Energy Used



- *Configurations have similar energy use*
- *Hybrid electric propulsion reduces fuel burn without increasing energy use*

Comparisons – LTO NOX

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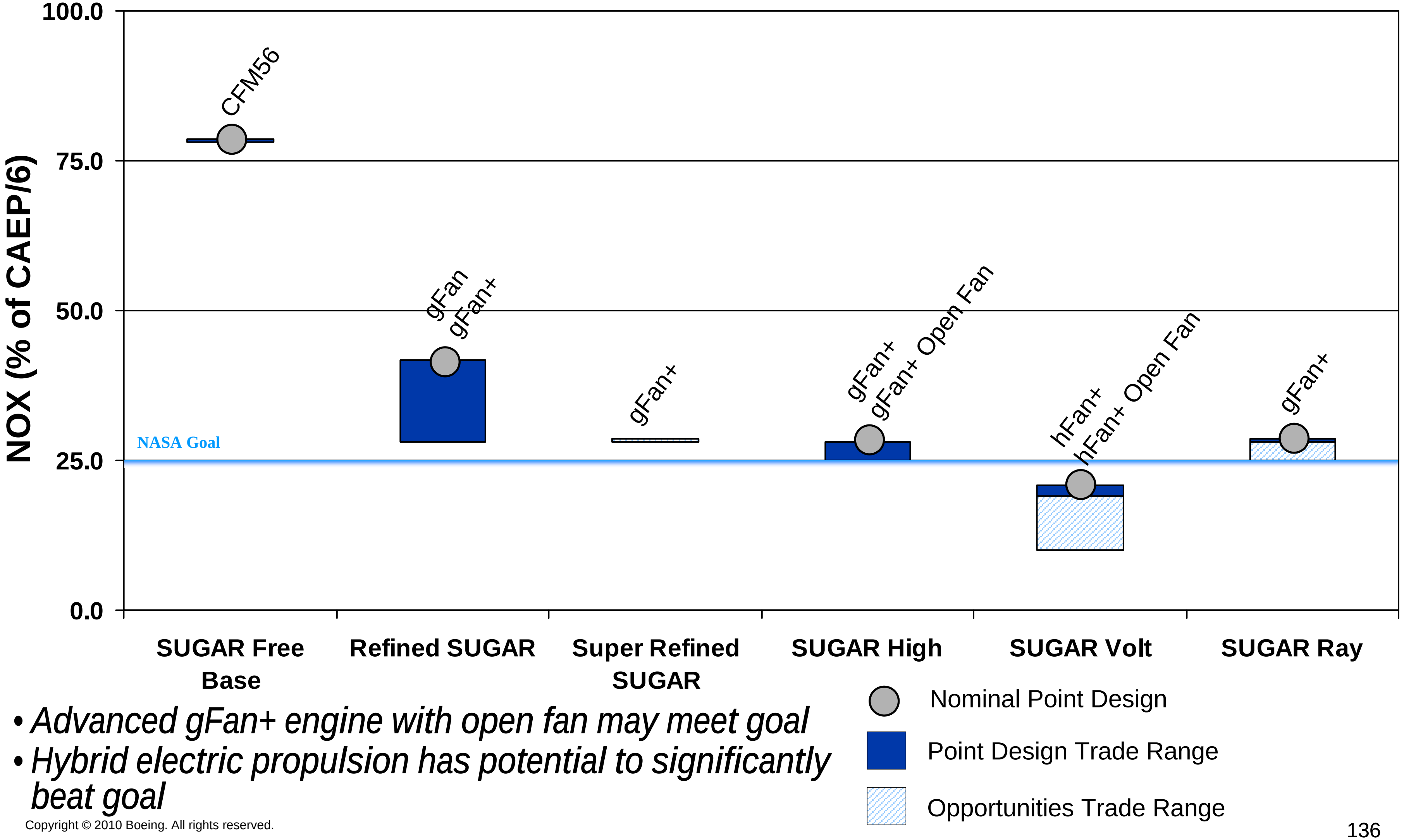
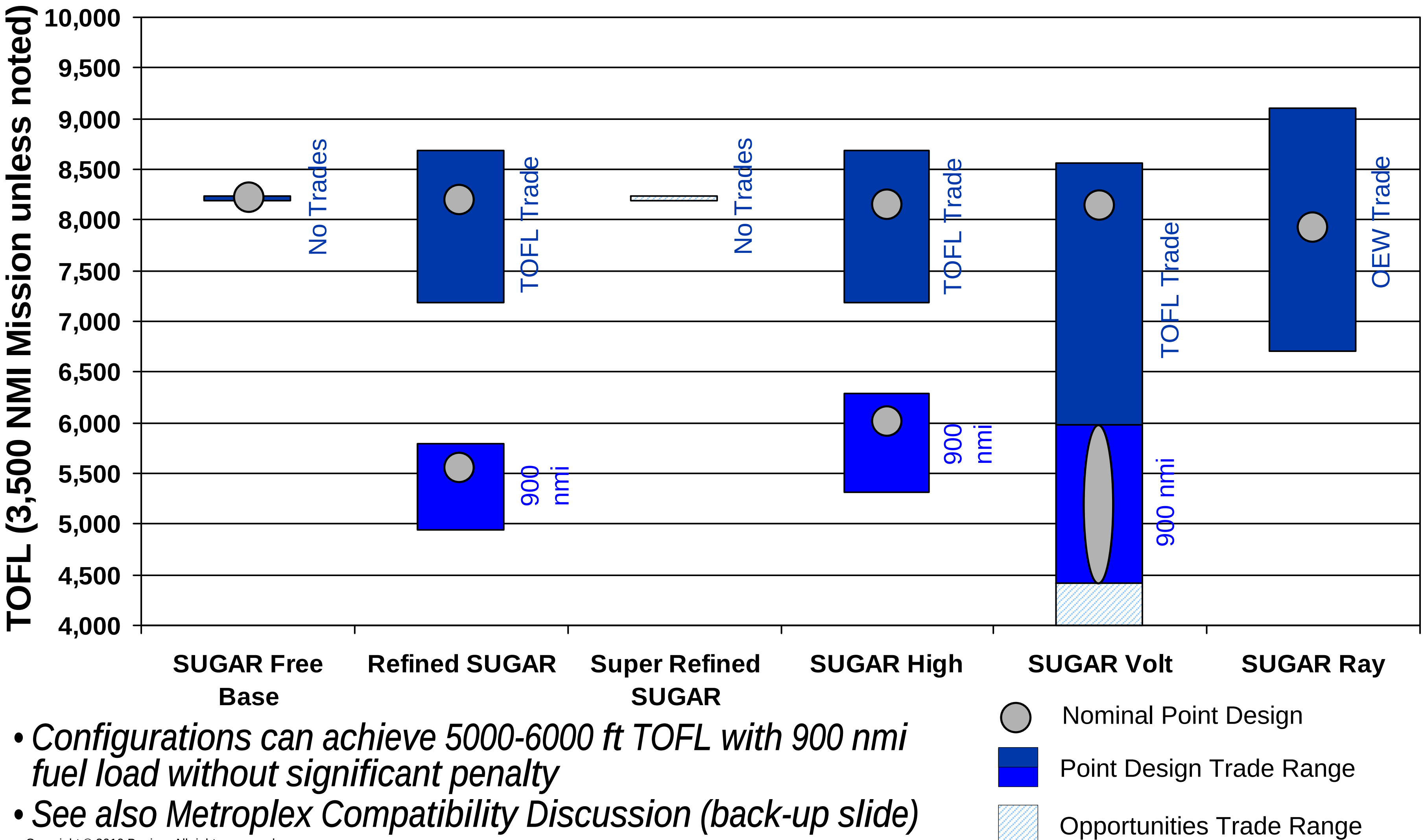


- *Advanced gFan+ engine with open fan may meet goal*
- *Hybrid electric propulsion has potential to significantly beat goal*

Comparisons – TOFL



- *Configurations can achieve 5000-6000 ft TOFL with 900 nmi fuel load without significant penalty*
- *See also Metroplex Compatibility Discussion (back-up slide)*

SUGAR Noise Comparison

Configuration	SUGAR Free	Refined SUGAR	Super Refined SUGAR	SUGAR High	SUGAR Volt	SUGAR Ray
Propulsion	CFM-56	gFan	gFan+	gFan+	hFan	gFan+
Relative Noise	0 db	-16 db	-22 db	-22 db	Potentially lower than gFan+	-37 db

Engine Acoustic Technologies:

- Passive noise absorbers
  - Bulk absorber materials
  - 2DOF and tailored absorbers
- Adv. Passive noise suppression
  - Adv. inlet/cold section treatments
  - Adv. Core & fan nozzle treatments
  - Inlet lip treatments
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Airframe Acoustic Technologies:

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- Inlet noise shielding from top of wing mounted engines
- Rear jet and exhaust fan duct noise shielding from rear deck/platform for flyover and approach noise reduction and twin verticals for lateral noise reduction (need to assess noise shielding increments) and exhaust nozzle designs for distributed jet noise source reduction from shielding
- Airframe noise reduction methods including wing plan-form (airfoil design), main gear fairings, lift & control surface treatments (sealing etc)
- Rear fan duct noise treatment methods

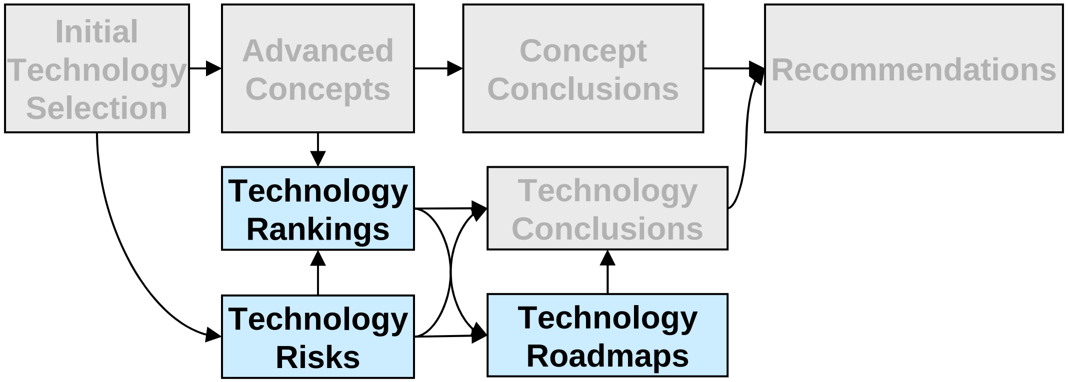
Vehicle Performance & Sizing Conclusions

- All advanced concepts (Refined, High, Volt, Ray) show promise for significant fuel burn improvement
- SUGAR High wing provides significant L/D improvement, but technologies and design optimization are required to reduce weight to make it competitive with conventional configurations. Has potential payoff, but with increased development risk.
- SUGAR Volt allows additional design and operational degrees of freedom and the potential to beat NASA goals
- SUGAR Volt Hybrid propulsion system is heavier, but reduces fuel burn, emissions, and noise
- SUGAR Ray HWB offers greatest potential noise reduction
- All advanced configurations could benefit from additional design optimization

SUGAR Phase 1 Final Review

11:00

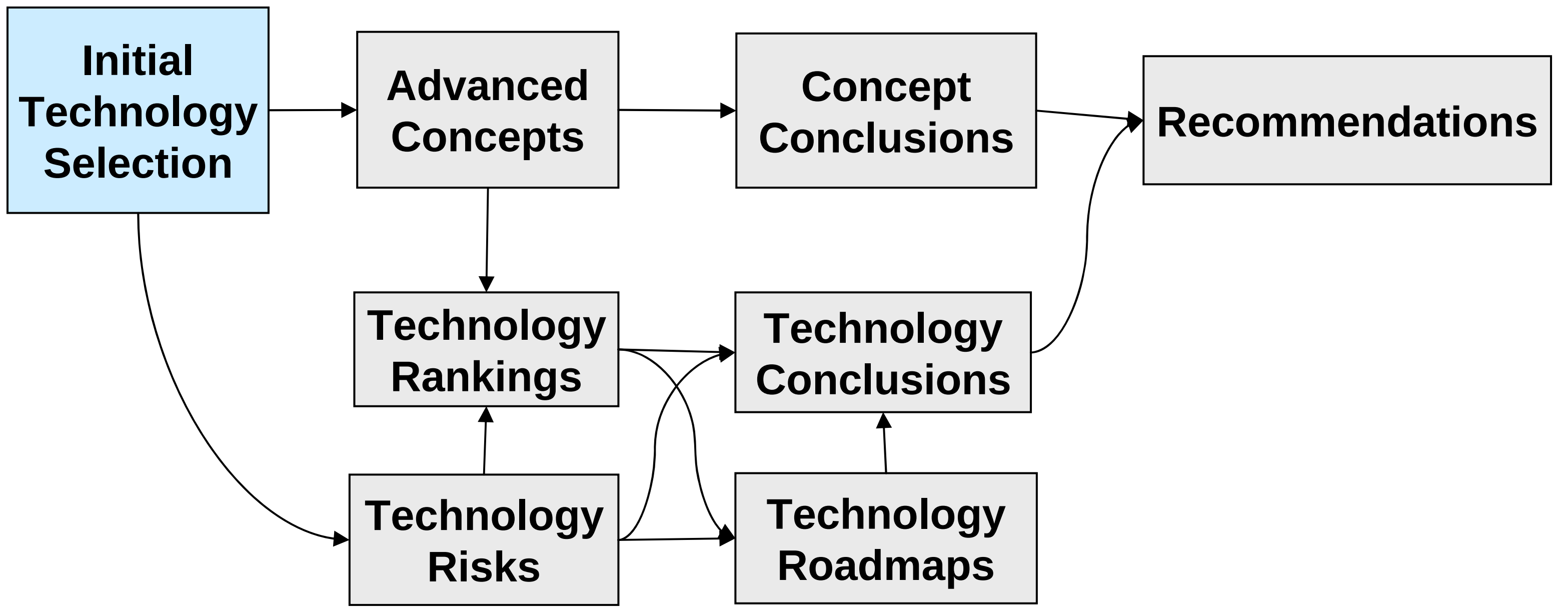
- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- Concept Performance and Sizing from 12-Month Review
- **Technology Activities**
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- Lunch
- Proprietary Session



Risk and Roadmapping

David J Paisley
Boeing Commercial Aircraft

SUGAR Phase 1 Process



Generation of Technology Groups

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- Georgia Tech led us through the grouping and ranking process
- The technology suites generated previously for each configuration were used as the starting point
- A comprehensive list containing approximately 75 technologies was generated
- These were then grouped into 26 technology groups for sensitivity analysis, ranking, and roadmapping

Propulsion Technology Areas

Propulsion Technology Summary

Configuration				
'N' SUGAR Free	'N+3' Refined SUGAR	'N+3' SUGAR High	'N+3' SUGAR Volt	'N+3' SUGAR Ray

Structures Technology Areas

Structures Technologies Summary

Configuration				
'N' SUGAR Free	'N+3' Refined SUGAR	'N+3' SUGAR High	'N+3' SUGAR Volt	'N+3' SUGAR Ray

Subsystem Technology Areas

Subsystems Technologies Summary

Configuration				
'N' SUGAR Free	'N+3' Refined SUGAR	'N+3' SUGAR High	'N+3' SUGAR Volt	'N+3' SUGAR Ray

Aero Technology Areas

Aero Technologies Summary

	Configuration				
	'N' SUGAR Free	'N+3' Refined SUGAR	'N+3' SUGAR High	'N+3' SUGAR Volt	'N+3' SUGAR Ray
Laminar Flow	None	Passive/Natural and Active Where Appropriate			
Riblets	None	Fuselage	Fuselage and Wing Where Appropriate		
Excrescence Drag	Conventional	Multi-Functional Structures, Reduced Fasteners, Reduced Flap Fairings			
Empennage	Conventional Size	Relaxed Static Stability & Increased C_{LMax} for reduced Size			
Airfoil Technology	Supercritical		Advanced Supercritical		Supercritical
Additional Technologies	None		Low Interference Nacelles Low Drag Strut Integration		Low Interference Nacelles Airframe Noise Shielding

Comprehensive list developed from technology tables

Technology
Low sulfur Jet-A, Synthetic or Biofuels
NextGen ATM Capable
High Performance Batteries
Modular Batteries (Combine with High Performance Batteries)
Natural Laminar Flow
Active Laminar Flow
Support for NLF (combine with aero Natural Laminar Flow)
Fuselage Riblets
Wing Riblets (Combine with Fuselage Riblets)
Relaxed Static Stability & Increased CLMax Empennage
Advanced Supercritical Airfoil
Low Interference Nacelles
Low Drag Strut
Airframe Noise Shielding
Active/Passive Aeroelastic Response for Load Control
Spanwise Load Control
Lightweight Wing Folds
Adv. Lightweight High Lift Systems
Very high bypass ratio turbofan with 2030 engine technologies
Very high bypass ratio turbofan with advanced engine tech.
Battery Gas Turbine Hybrid (SUGAR High tech level)
TAPS
Next Gen TAPS (Combine with TAPS)
Additional advanced passive engine treatments
Active engine noise control/fluidics
Bundle together advanced material technologies
Enable Lightweight Materials Coatings
Energy Harvesting Coatings
Thermal Management Coatings
More Lightweight Interiors
Environmentally Compliant Manufacturing
Adv. Composites incl. Hybrid Polymer
Adv. Metals
Adv. Ceramics
Drag Reduction Coatings
Bundle together advanced structures technologies
Reduced Fasteners
Reduced Flap Fairings
Reliability Based Design
Robust/Unitized
Conformal, Gapless, Adaptive Structures
Adv. Joining
On-board Structurally Integrated SHM, Advanced NDE/NDI
Maximize Flight Control Integration
Adv. Material Forms
Adv. Noncircular Fuselage
Bundle together advanced engine materials
Bundle together advanced subsystem technologies
Adaptive Power Management
Diesel APU
EMA Actuators
Fiberoptic Control Architecture
Lightweight Thermal Techngology
High Conductivity, Lightweight Wiring
Integrated Computing Networks
Open Fan
Bundle Together Multifunction Structures Technologies
Multi-Functional Structures with subsystems
Multi-Functional Subsystems with structures
Structurally Integrated Thermal and Electrical Energy Management
More Tolerant Systems & Dual Use Structure
Struct. Integrated Systems (Wiring)
Copper Wiring w/ Current return networks
Airframe Acoustic Technologies

26 Technology groups created for roadmapping

Technology	Risk ID
Low sulfur Jet-A, Synthetic or Biofuels	1
NextGen ATM Capable	2
High Performance Modular Batteries	3
Natural Laminar Flow	4
Fuselage & Wing Riblets	5
Relaxed Static Stability & Increased CLMax Empennage	6
Advanced Supercritical Airfoil	7
Low Interference Nacelles	8
Low Drag Strut (no interference, laminar flow in NLF)	9
Airframe Noise Shielding	10
Active/Passive Aeroelastic Response for Load Control	11
Lightweight Wing Folds	12
Adv. Lightweight High Lift Systems	13
Very high bypass ratio turbofan with 2030 engine technologies	14
Very high bypass ratio turbofan with advanced engine tech.	15
Battery Gas Turbine Hybrid (SUGAR High tech level)	16
TAPS & Next Generation TAPS	17
Additional advanced passive treatments	18
Active noise control/fluidics	19
Bundle together advanced material technologies	20
Bundle together advanced structures technologies	21
Bundle together advanced engine materials	22
Bundle together advanced subsystem technologies	23
Open Fan	24
Bundle together multi-functional structures technologies	25
Airframe acoustic technologies	26

Figure 7.1 – Generation of Technology Groups

Candidate Technologies

Candidate Technologies by Concept

Technology	Risk ID	SUGAR Concepts				
		SUGAR Free	Refined SUGAR	SUGAR High	SUGAR Volt	SUGAR Ray
Low sulfur Jet-A, Synthetic or Biofuels	1	-	X	X	X	X
NextGen ATM Capable	2	-	X	X	X	X
High Performance Modular Batteries	3	-			X	
Natural Laminar Flow	4	-	X	X	X	X
Fuselage & Wing Riblets	5	-	X	X	X	X
Relaxed Static Stability & Increased CLMax Empennage	6	-	X	X	X	X
Advanced Supercritical Airfoil	7	-		X	X	
Low Interference Nacelles	8	-		X	X	X
Low Drag Strut (no interference, laminar flow in NLF)	9	-		X	X	
Airframe Noise Shielding	10	-				X
Active/Passive Aeroelastic Response for Load Control	11	-	X	X	X	X
Lightweight Wing Folds	12	-		X	X	X
Adv. Lightweight High Lift Systems	13	-		X	X	
Very high bypass ratio turbofan with 2030 engine technologies	14	-	X	X	X	X
Very high bypass ratio turbofan with advanced engine tech.	15	-		X	X	X
Battery Gas Turbine Hybrid (SUGAR High tech level)	16	-			X	
TAPS & Next Generation TAPS	17	-	X	X	X	X
Additional advanced passive treatments	18	-		X	X	X
Active noise control/fluidics	19	-		X	X	X
Bundle together advanced material technologies	20	-	X	X	X	X
Bundle together advanced structures technologies	21	-	X	X	X	X
Bundle together advanced engine materials	22	-	X	X	X	X
Bundle together advanced subsystem technologies	23	-	X	X	X	X
Open Fan	24	-		X	X	
Bundle together multi-functional structures technologies	25	-	X	X	X	X
Airframe acoustic technologies	26		X	X	X	X

Almost all technologies applicable to SUGAR Volt – the best performing airplane for fuel burn and emissions

Table 7.1 – Candidate Technologies by Concept

Candidate Technologies by NASA N+3 Goal

BCA – Advanced Concepts

BR&T – Platform Performance Technology

		NASA N+3 Goals				
Technology	**Risk ID**	**Fuel Burn**	**LTO Nox**	**Noise**	**TOFL**	**Cruise Emissions**
Low sulfur Jet-A, Synthetic or Biofuels	1		Low-Med			High (biofuels only)
NextGen ATM Capable	2	High				High
High Performance Modular Batteries	3	High	Med	Med	Low	High
Natural Laminar Flow	4	High				High
Fuselage & Wing Riblets	5	Med				Med
Relaxed Static Stability & Increased CLMax Empennage	6	Med				Med
Advanced Supercritical Airfoil	7	Med				Med
Low Interference Nacelles	8	Med				Med
Low Drag Strut (no interference, laminar flow in NLF)	9	Med				Med
Airframe Noise Shielding	10			High		
Active/Passive Aeroelastic Response for Load Control	11	High-Med				
Lightweight Wing Folds	12	Low				Low
Adv. Lightweight High Lift Systems	13	Low		Med	High	Low
Very high bypass ratio turbofan with 2030 engine technologies	14	High	High	High		High
Very high bypass ratio turbofan with advanced engine tech.	15	High	High	High		High
Battery Gas Turbine Hybrid (SUGAR High tech level)	16	High				High
TAPS & Next Generation TAPS	17	Med	High			Med
Additional advanced passive treatments	18			High		
Active noise control/fluidics	19			High		
Bundle together advanced material technologies	20	High				High
Bundle together advanced structures technologies	21	High				High
Bundle together advanced engine materials	22	High				High
Bundle together advanced subsystem technologies	23	High				High
Open Fan	24	High		-Med		HIgh
Bundle together multi-functional structures technologies	25	High				High
Airframe acoustic technologies	26			Med		

Most technologies focused on fuel burn/emissions

Table 7.2 – Candidate Technologies by NASA N+3 goal

Estimated TRL

Technology	Risk ID	Current TRL Level
Low sulfur Jet-A, Synthetic or Biofuels	1	8=syn 6=bio
NextGen ATM Capable	2	6+
High Performance Modular Batteries	3	2
Natural Laminar Flow	4	5
Fuselage & Wing Riblets	5	5
Relaxed Static Stability & Increased CLMax Empennage	6	4
Advanced Supercritical Airfoil	7	4
Low Interference Nacelles	8	3
Low Drag Strut (no interference, laminar flow in NLF)	9	2 to 3
Airframe Noise Shielding	10	4
Active/Passive Aeroelastic Response for Load Control	11	4
Lightweight Wing Folds	12	3
Adv. Lightweight High Lift Systems	13	3
Very high bypass ratio turbofan with 2030 engine technologies	14	3
Very high bypass ratio turbofan with advanced engine tech.	15	2
Battery Gas Turbine Hybrid (SUGAR High tech level)	16	1
TAPS & Next Generation TAPS	17	3
Additional advanced passive treatments	18	3
Active noise control/fluidics	19	2
Bundle together advanced material technologies	20	4
Bundle together advanced structures technologies	21	3 to 5
Bundle together advanced engine materials	22	2
Bundle together advanced subsystem technologies	23	2 to 5
Open Fan	24	2 to 3
Bundle together multi-functional structures technologies	25	2 to 5
Airframe acoustic technologies	26	4

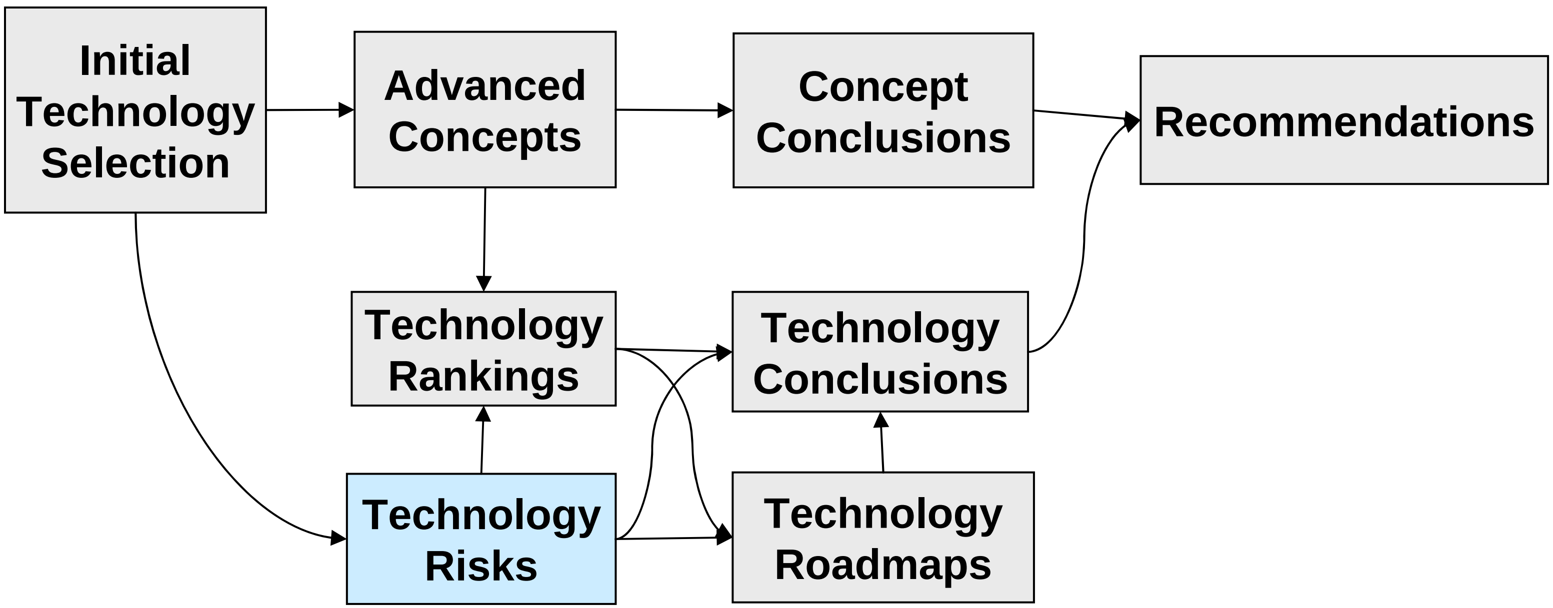
Majority around TRL 2-5

Table 7.3 – Estimated TRL

SUGAR Phase 1 Process

BCA – Advanced Concepts

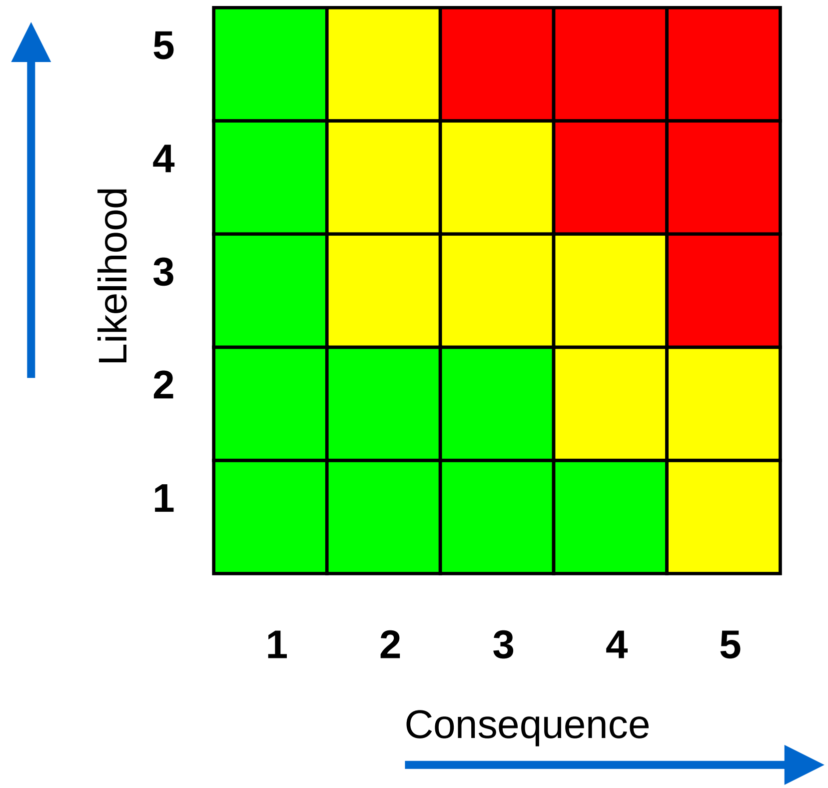
BR&T – Platform Performance Technology



Risk Map

Technology development reduces risk by reducing likelihood of failure

Increasing Likelihood of Risk Item Occurring



High

Moderate

Low

Increasing Impact if Risk Item Occurs

Figure 7.23 – Risk Map

Candidate Technologies Risk Assessment

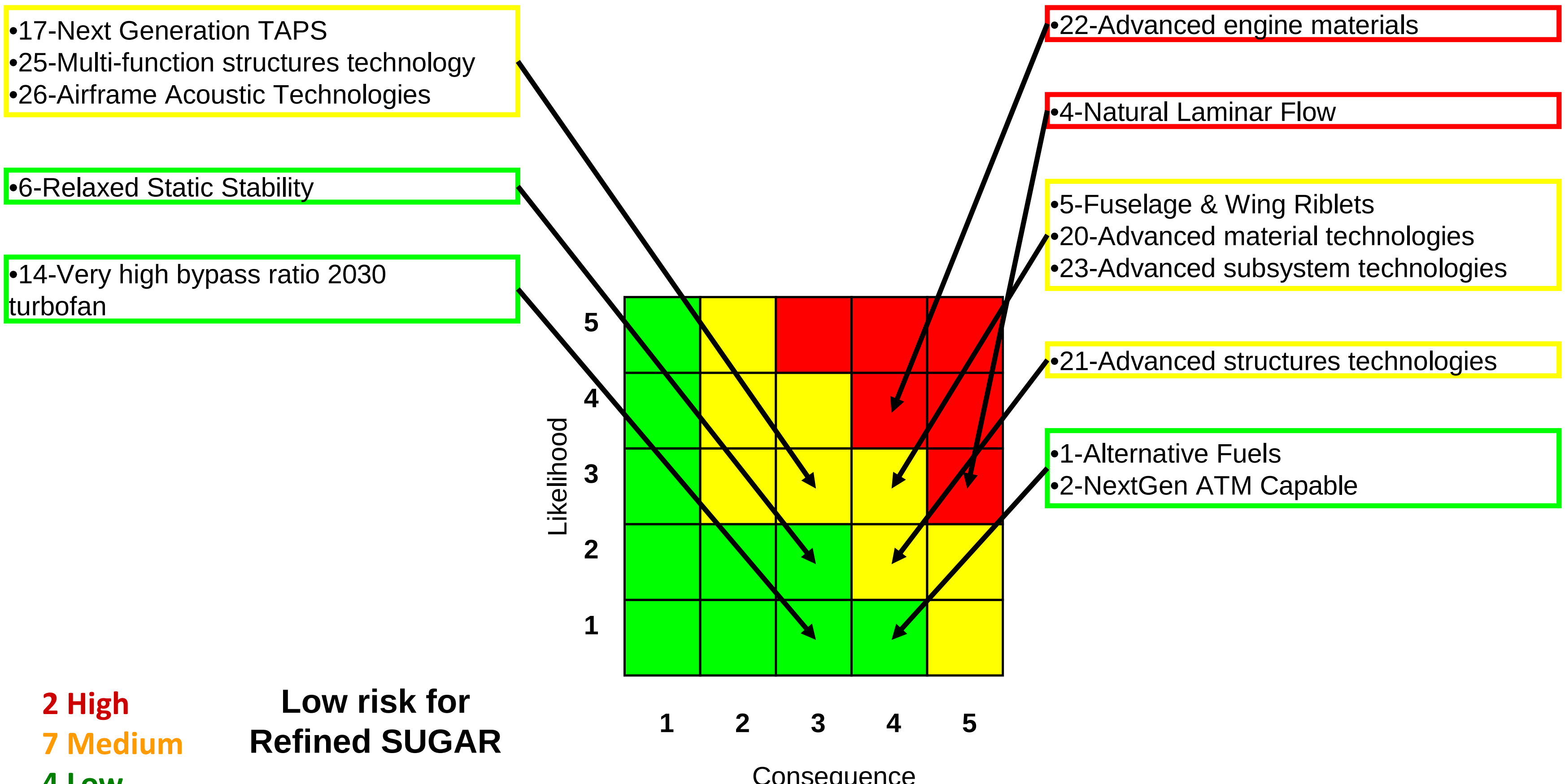
Technology	Risk ID	Technical Risk High	Med	Low	Consequence (1-5)	Likelihood of Failure (1-5)
Low sulfur Jet-A, Synthetic or Biofuels	1		X Prod	X Int	4	1
NextGen ATM Capable	2			X	4	1
High Performance Modular Batteries	3	X			5	5
Natural Laminar Flow	4	X			5	3
Fuselage & Wing Riblets	5		X		4	3
Relaxed Static Stability & Increased CLMax Empennage	6			X	3	2
Advanced Supercritical Airfoil	7		X		4	2
Low Interference Nacelles	8		X		3	3
Low Drag Strut (no interference, laminar flow in NLF)	9		X		4	3
Airframe Noise Shielding	10		X		3	3
Active/Passive Aeroelastic Response for Load Control	11		X		5 (HV) 3(oth)	2
Lightweight Wing Folds	12			X	3	1
Adv. Lightweight High Lift Systems	13		X		2	3
Very high bypass ratio turbofan with 2030 engine technologies	14			X	3	1
Very high bypass ratio turbofan with advanced engine tech.	15		X		3	3
Battery Gas Turbine Hybrid (SUGAR High tech level)	16	X			5	4
TAPS & Next Generation TAPS	17		X		3	3
Additional advanced passive treatments	18		X		2	3
Active noise control/fluidics	19	X			4	4
Bundle together advanced material technologies	20		X		4	2
Bundle together advanced structures technologies	21		X		4	2
Bundle together advanced engine materials	22	X			4	4
Bundle together advanced subsystem technologies	23		X		4	3
Open Fan	24		X		3	3
Bundle together multi-functional structures technologies	25		X		3	3
Airframe acoustic technologies	26		X		3	3

Important to calibrate risks to a common scale

Table 7.4 – Candidate Technologies Risk Assessment

Risk Maps by Configuration

Risk Map for Refined SUGAR



2 High
7 Medium
4 Low

Low risk for Refined SUGAR

Figure 7.24 – Risk Map for Refined SUGAR

Risk Map for SUGAR High

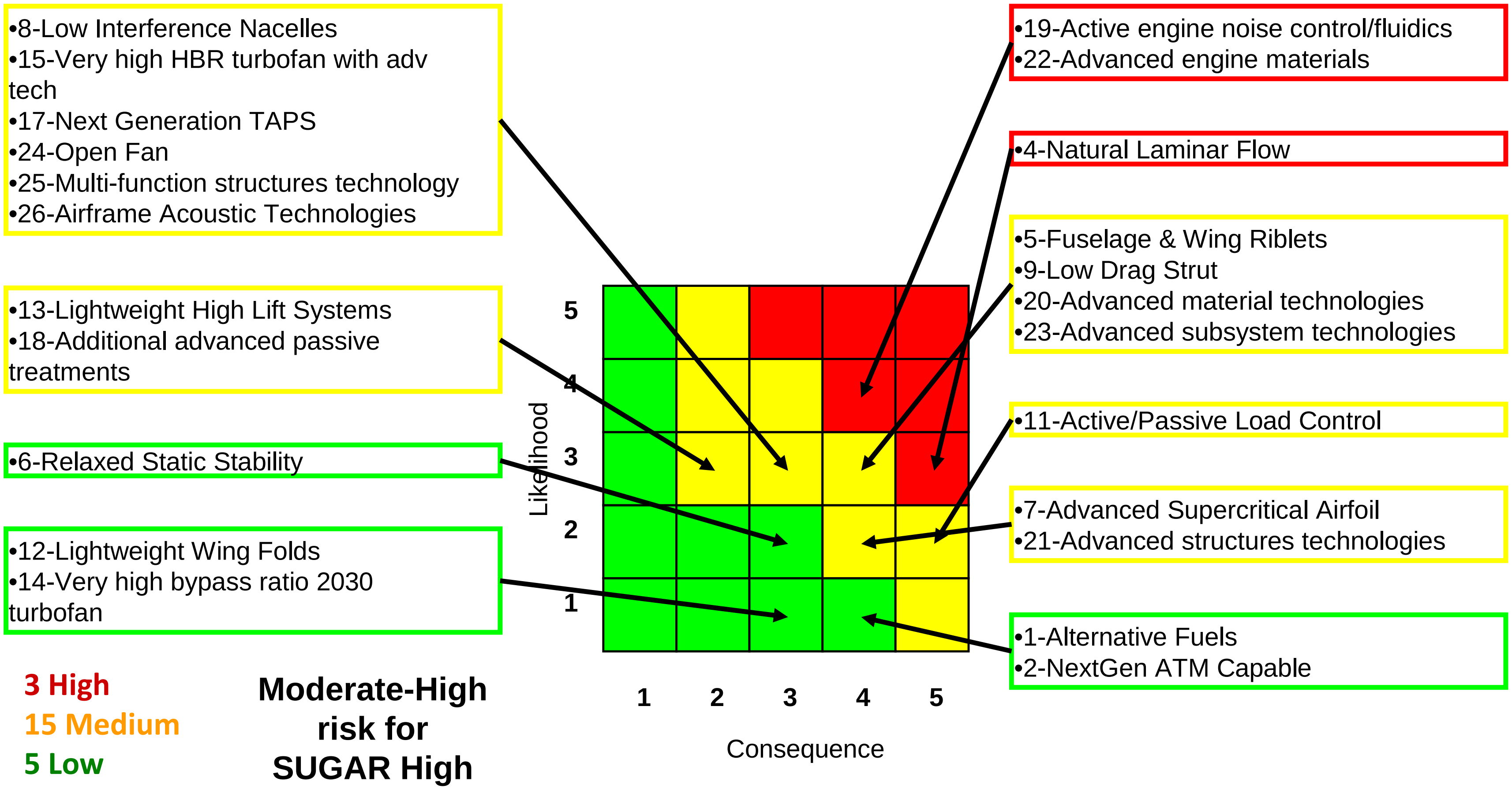


Figure 7.25 – Risk Map for SUGAR High

Risk Map for SUGAR Volt

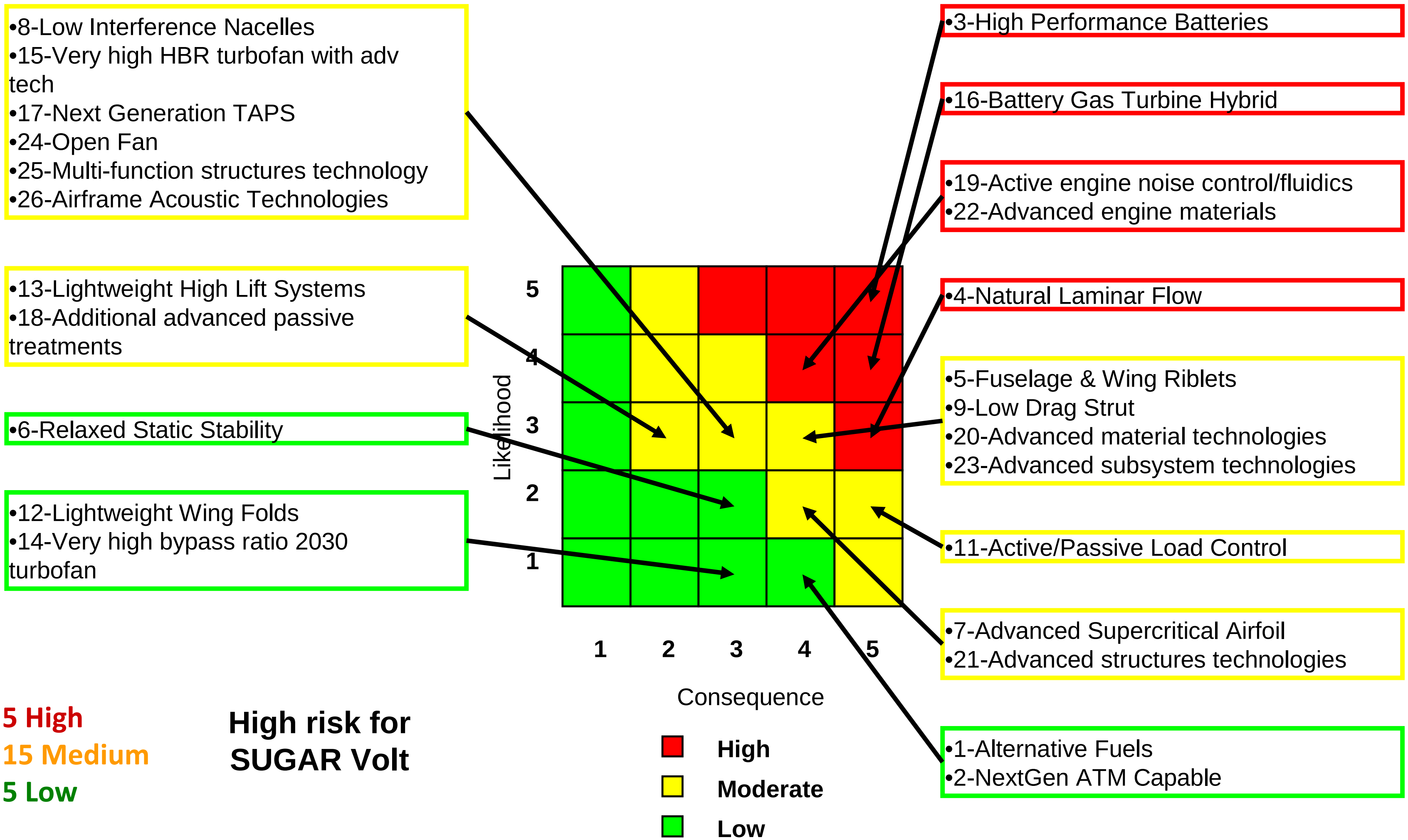


Figure 7.26 – Risk Map for SUGAR Volt

Risk Map for SUGAR Ray

- 8-Low Interference Nacelles
- 10-Airframe Noise Shielding
- 15-Very high HBR turbofan with adv tech
- 17-Next Generation TAPS
- 25-Multi-function structures technology
- 26-Airframe Acoustic Technologies

- 18-Additional advanced passive treatments

- 6-Relaxed Static Stability

- 12-Lightweight Wing Folds
- 14-Very high bypass ratio 2030 turbofan

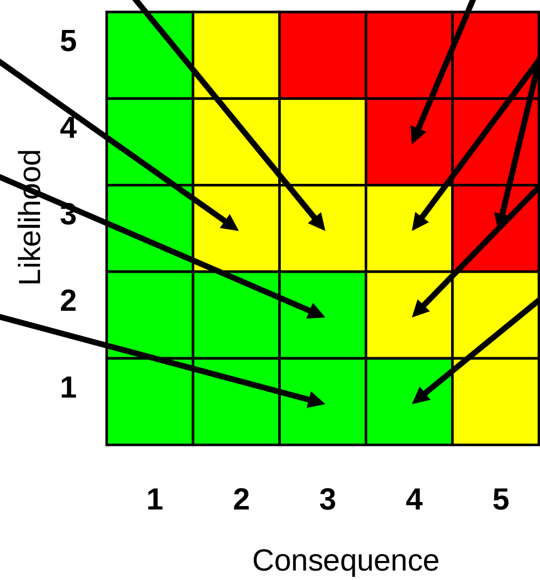
- 19-Active engine noise control/fluidics
- 22-Advanced engine materials

- 4-Natural Laminar Flow

- 5-Fuselage & Wing Riblets
- 20-Advanced material technologies
- 23-Advanced subsystem technologies

- 21-Advanced structures technologies

- 1-Alternative Fuels
- 2-NextGen ATM Capable



3 High
11 Medium
5 Low

Moderate risk for SUGAR Ray

Figure 7.27 – Risk Map for SUGAR Ray

Risk Maps by Technology

Risk Map for Fuel Burn Technologies

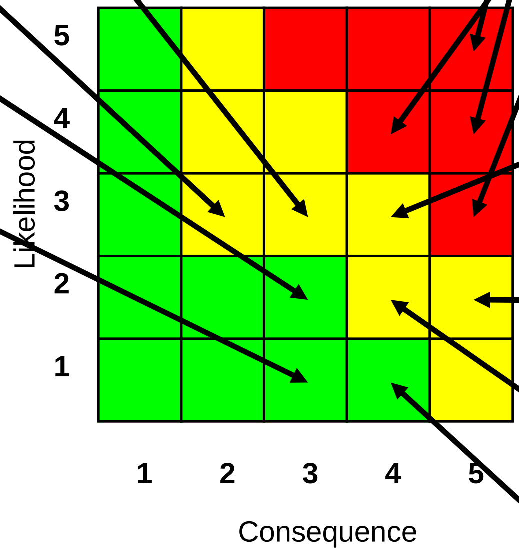
BCA – Advanced Concepts   BR&T – Platform Performance Technology

- •8-Low Interference Nacelles
- •15-Very high HBR turbofan with adv tech
- •17-Next Generation TAPS
- •24-Open Fan
- •25-Multi-function structures technology

- •13-Lightweight High Lift Systems

- •6-Relaxed Static Stability

- •12-Lightweight Wing Folds
- •14-Very high bypass ratio 2030 turbofan



- •3-High Performance Batteries

- •16-Battery Gas Turbine Hybrid

- •22-Advanced engine materials

- •4-Natural Laminar Flow

- •5-Fuselage & Wing Riblets
- •9-Low Drag Strut
- •20-Advanced material technologies
- •23-Advanced subsystem technologies

- •11-Active/Passive Load Control

- •7-Advanced Supercritical Airfoil
- •21-Advanced structures technologies

- •2-NextGen ATM Capable

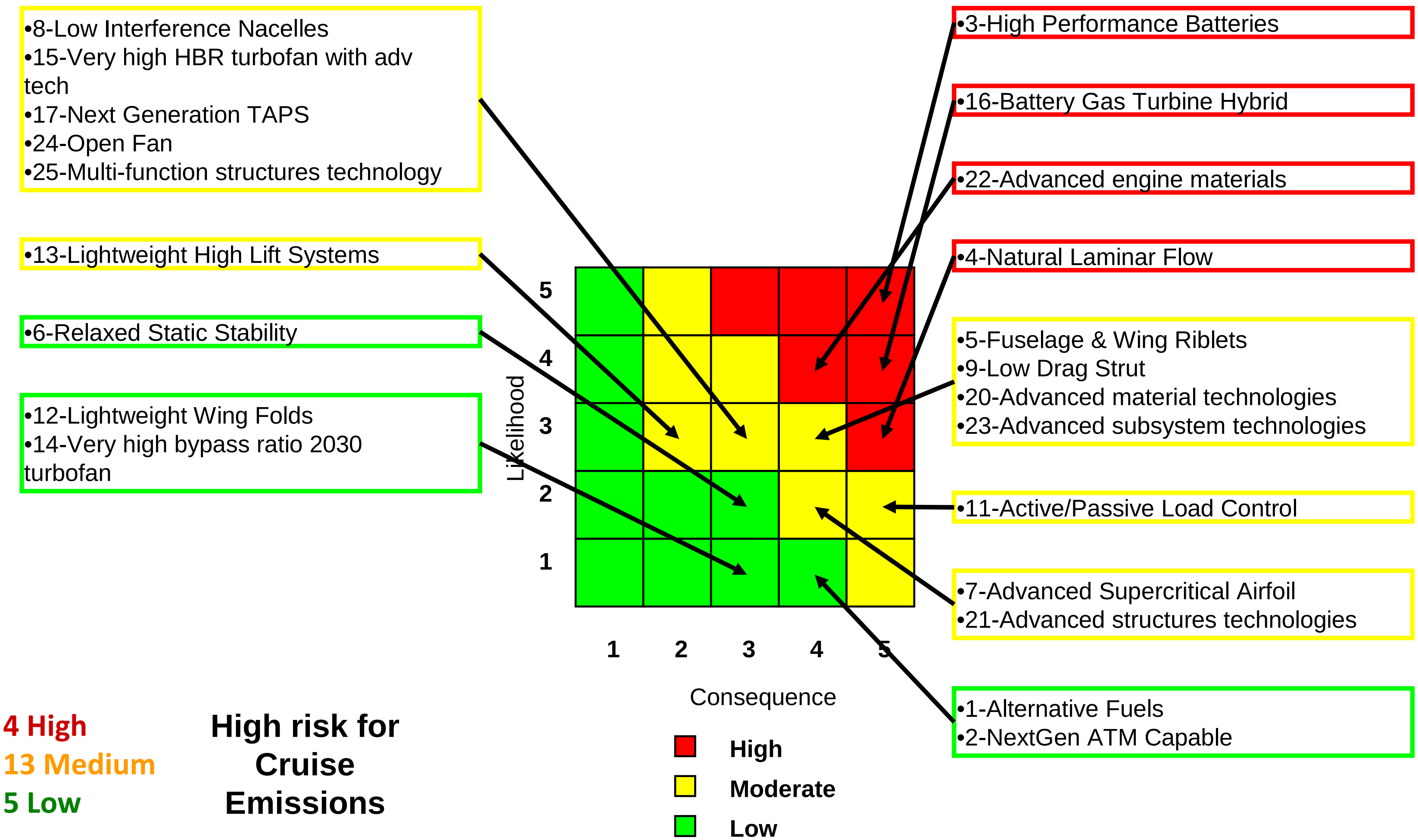
4 High
13 Medium
4 Low

High risk for Fuel Burn

Figure 7.28 – Risk Map for the Fuel Burn Technologies

Risk Map for Cruise Emissions Technologies

BCA – Advanced Concepts | BR&T – Platform Performance Technology



4 High
13 Medium
5 Low

High risk for Cruise Emissions

Figure 7.29 – Risk Map for the Cruise Emissions Technologies

Risk Map for LTO NOx Technologies

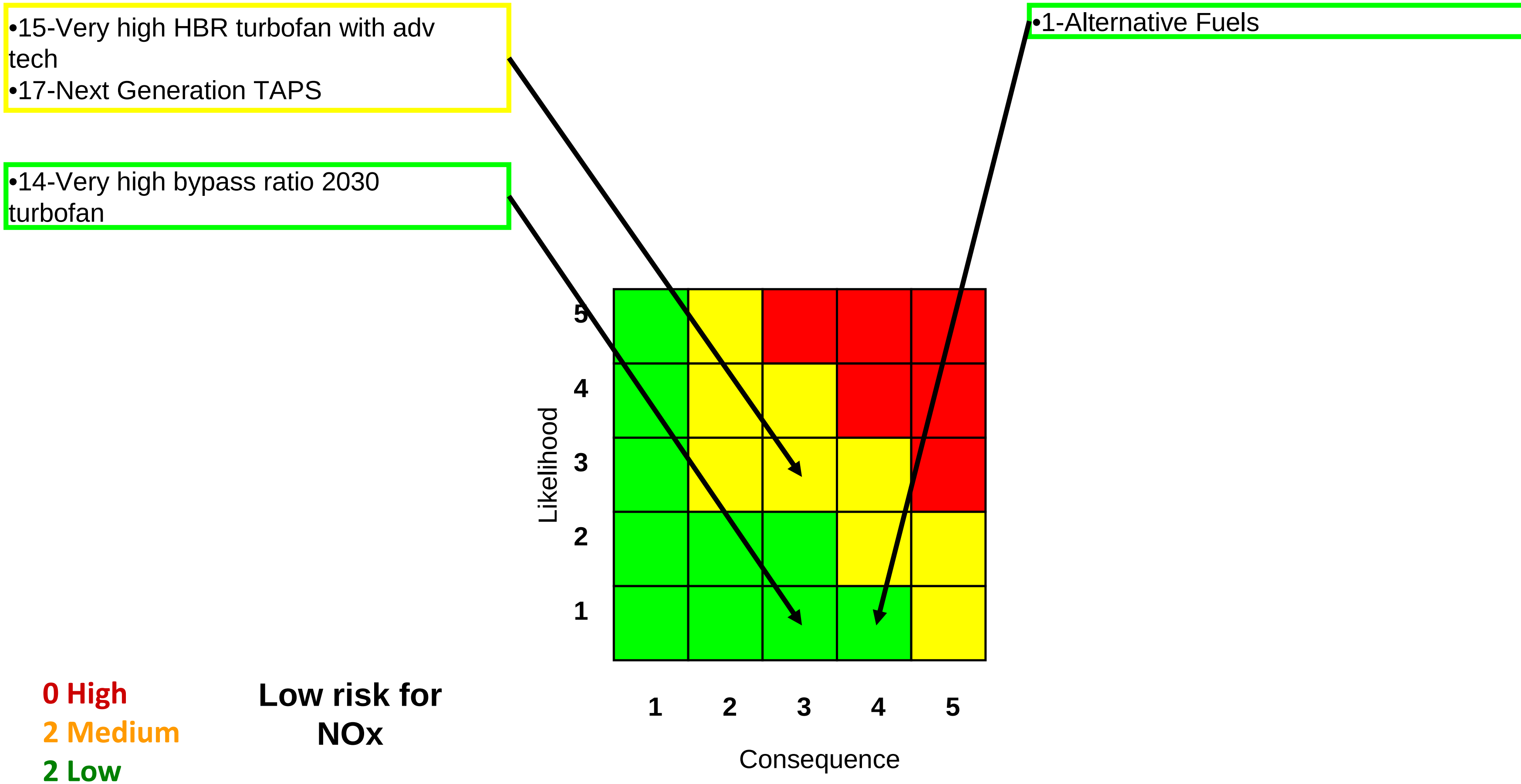


Figure 7.30 – Risk Map for the LTO NOx Technologies

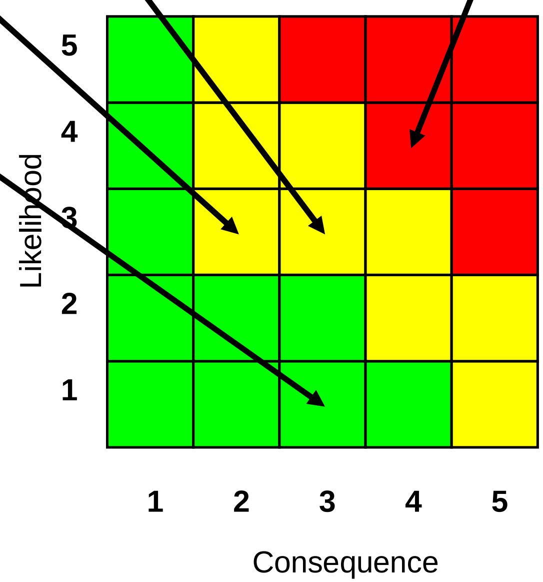
Risk Map for Noise Technologies

•10-Airframe Noise Shielding
•15-Very high HBR turbofan with adv tech
•24-Open Fan
•26-Airframe Acoustic Technologies

•13-Lightweight High Lift Systems
•18-Additional advanced passive treatments

•14-Very high bypass ratio 2030 turbofan

•19-Active engine noise control/fluidics



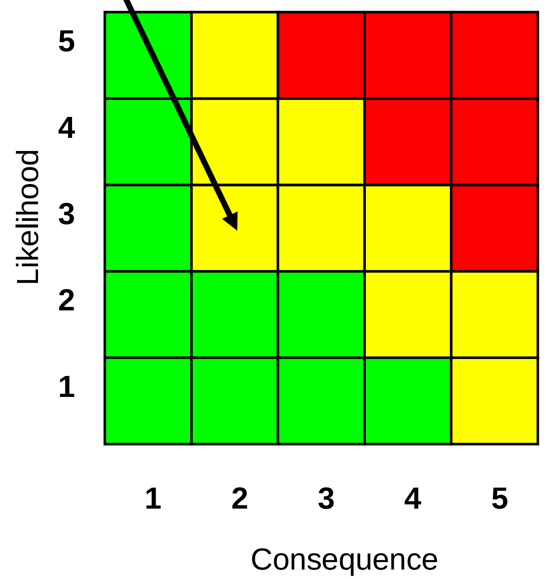
1 High
6 Medium
1 Low

Low risk for Noise

Figure 7.31 – Risk Map for the Noise Technologies

Risk Map for TOFL Technologies

•13-Lightweight High Lift Systems

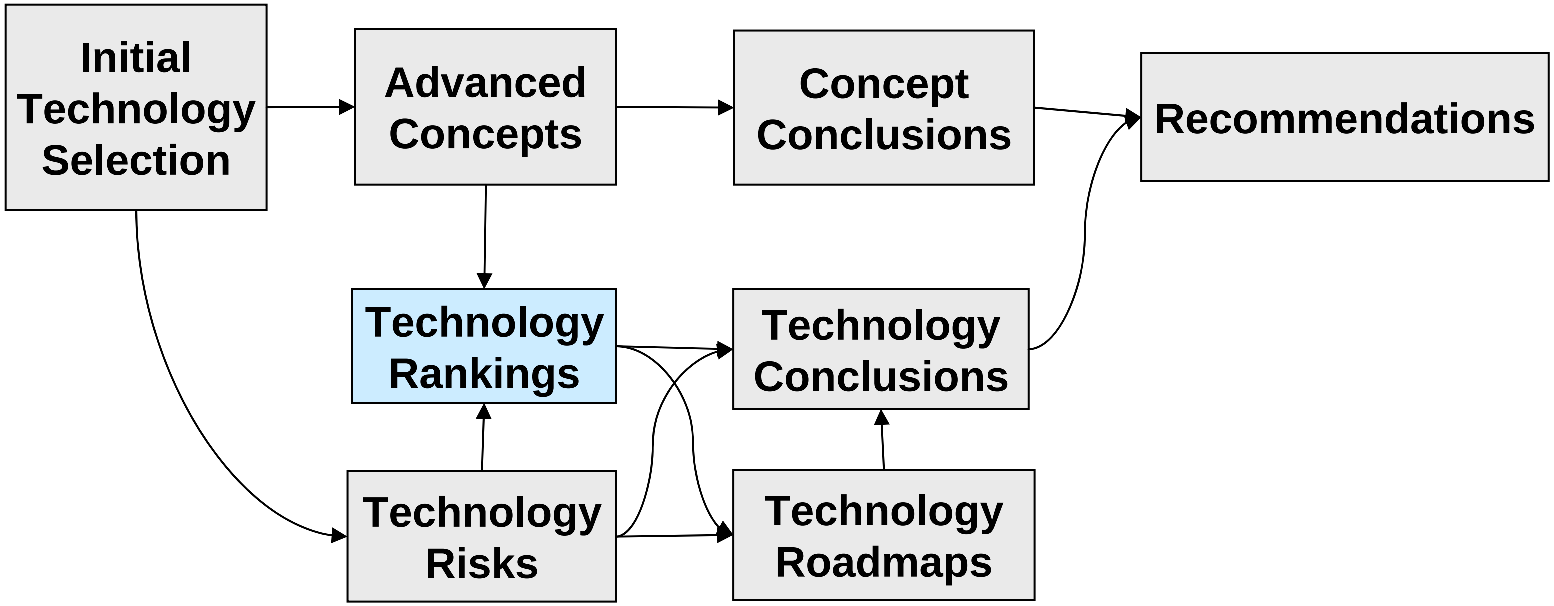


0 High
1 Medium
0 Low

Low risk for TOFL

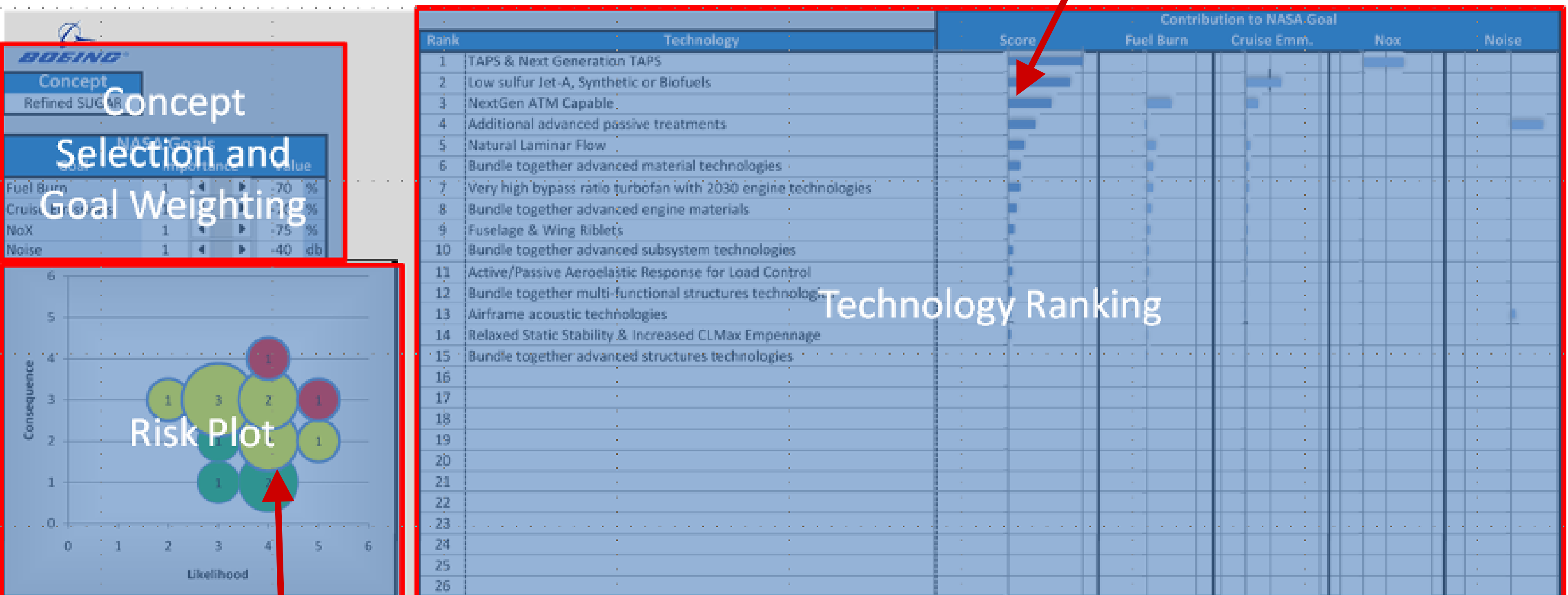
Figure 7.32 – Risk Map for the TOFL Technologies

Technology Ranking



Technology Ranking Dashboard Layout

Ordered by descending overall score



Number of risks included in circle

Figure 7.2 – Technology Ranking Dashboard Layout

Technology Ranking by Configuration and Goal

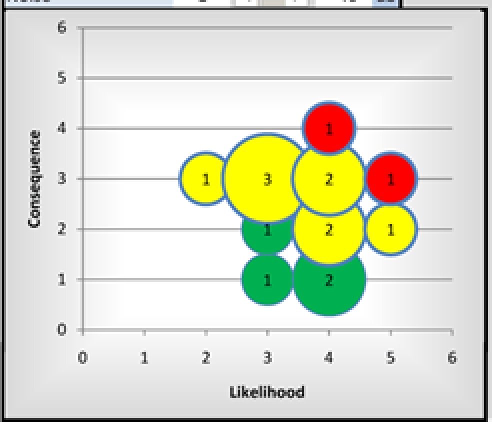
Refined SUGAR

Refined SUGAR - Equal Goal Weighting

BOEING

Concept
Refined SUGAR

NASA Goals			
Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	1	-70	%
NoX	1	-75	%
Noise	1	-40	db



Rank	Technology
1	TAPS & Next Generation TAPS
2	Low sulfur Jet-A, Synthetic or Biofuels
3	NextGen ATM Capable
4	Additional advanced passive treatments
5	Natural Laminar Flow
6	Bundle together advanced material technologies
7	Very high bypass ratio turbofan with 2030 engine technologies
8	Bundle together advanced engine materials
9	Fuselage & Wing Riblets
10	Bundle together advanced subsystem technologies
11	Active/Passive Aeroelastic Response for Load Control
12	Bundle together multi-functional structures technologies
13	Airframe acoustic technologies
14	Relaxed Static Stability & Increased CLMax Empennage
15	Bundle together advanced structures technologies
16	
17	
18	
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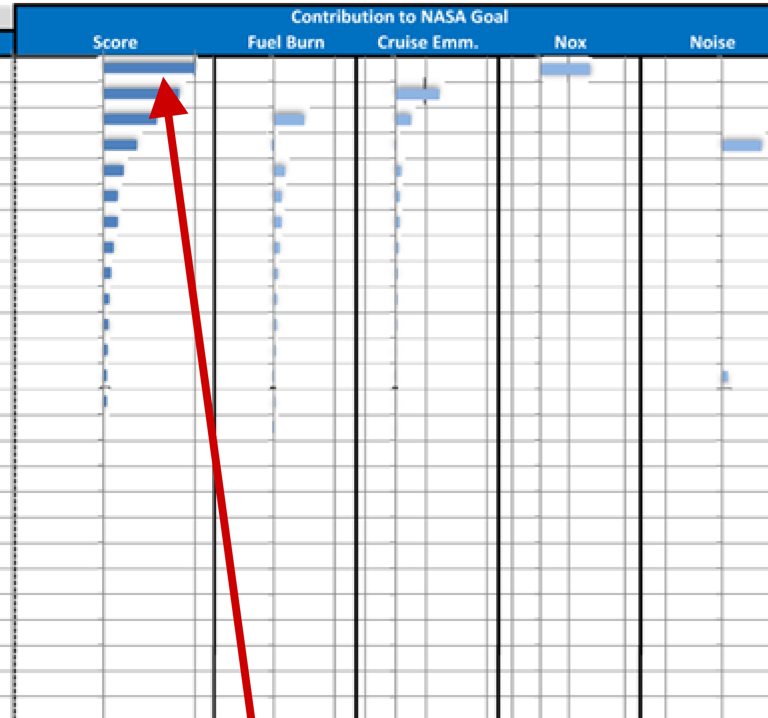
23	
24	
25	
26	



With equal ranking, TAPS has a greater impact in its primary application area than any other individual technology

Figure 7.3 – Refined SUGAR Technology Ranking with Equal Goal Weighting

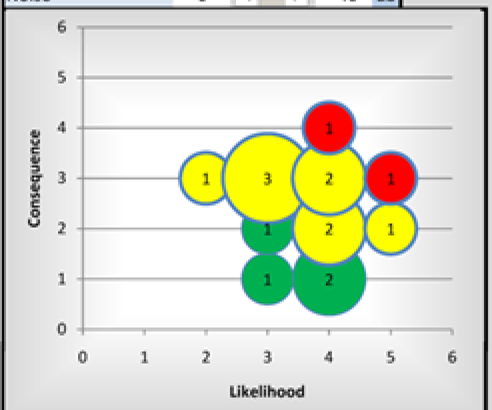
Refined SUGAR - Fuel Burn Goal

BCA – Advanced Concepts

BR&T – Platform Performance Technology

Concept
Refined SUGAR

NASA Goals			
Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	0	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	NextGen ATM Capable					
2	Natural Laminar Flow					
3	Bundle together advanced material technologies					
4	Very high bypass ratio turbofan with 2030 engine technologies					
5	Bundle together advanced engine materials					
6	Fuselage & Wing Riblets					
7	Bundle together advanced subsystem technologies					
8	Active/Passive Aeroelastic Response for Load Control					
9	Bundle together multi-functional structures technologies					
10	Relaxed Static Stability & Increased CLMax Empennage					
11						
12						
13	Bundle together advanced structures technologies					
14	Airframe acoustic technologies					
15	Additional advanced passive treatments					
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						

Non-relevant technologies blanked out

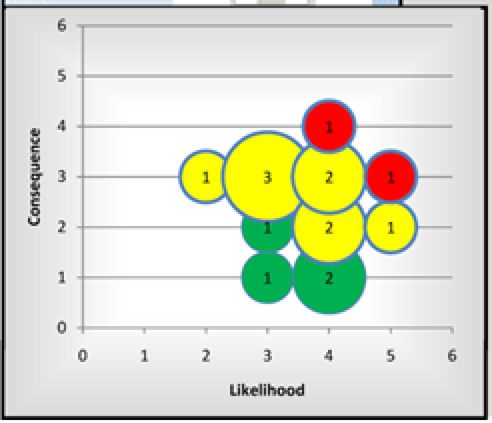
Some technologies have negative impact on some goals

Figure 7.4 – Refined SUGAR Technology Ranking for Fuel Burn Goal

Refined SUGAR - Cruise Emissions Goal

Concept
Refined SUGAR

NASA Goals			
Goal	Importance	Value	
Fuel Burn	0	-70	%
Cruise Emissions	1	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	Low sulfur Jet-A, Synthetic or Biofuels					
2	NextGen ATM Capable					
3	Natural Laminar Flow					
4	Bundle together advanced material technologies					
5	Very high bypass ratio turbofan with 2030 engine technologies					
6	Bundle together advanced engine materials					
7	Fuselage & Wing Riblets					
8	Bundle together advanced subsystem technologies					
9	Active/Passive Aeroelastic Response for Load Control					
10	Bundle together multi-functional structures technologies					
11	Relaxed Static Stability & Increased CLMax Empennage					
12						
13	Bundle together advanced structures technologies					
14	Airframe acoustic technologies					
15	Additional advanced passive treatments					
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						

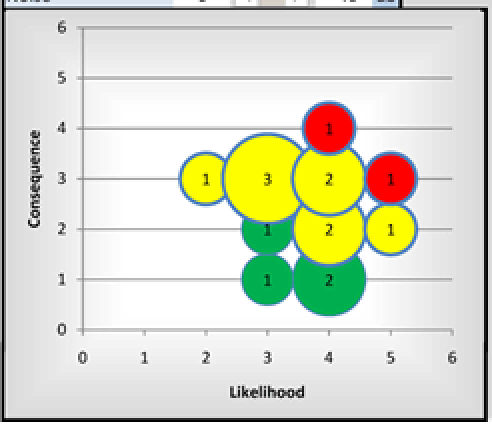
Very similar to Fuel Burn, but with added impact of biofuels

Figure 7.5 – Refined SUGAR Technology Ranking for Cruise Emissions Goal

Refined SUGAR - NOx Reduction Goal

Concept
Refined SUGAR

NASA Goals			
Goal	Importance	Value	
Fuel Burn	0	-70	%
Cruise Emissions	0	-70	%
NoX	1	-75	%
Noise	0	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	TAPS & Next Generation TAPS					
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						

Figure 7.6 – Refined SUGAR Technology Ranking for NOx Reduction Goal

Refined SUGAR - Noise Reduction Goal

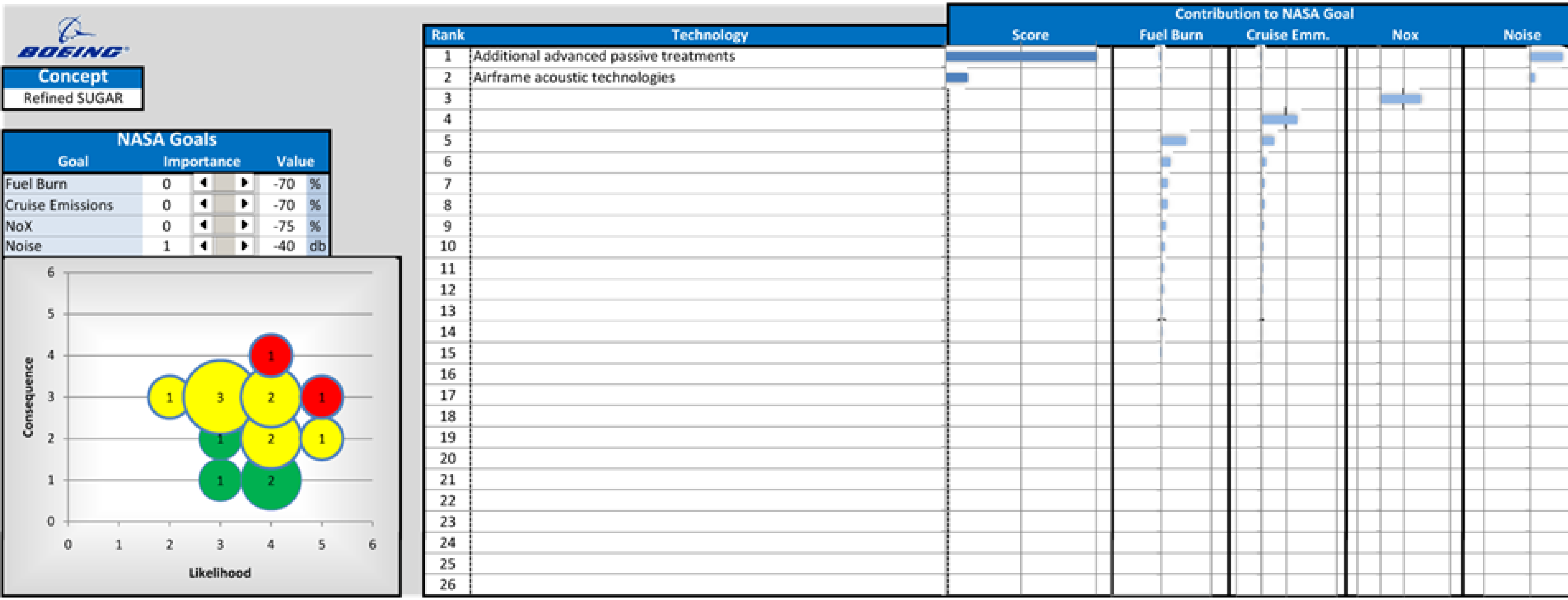


Figure 7.7 – Refined SUGAR Technology Ranking for Noise Reduction Goal

Risk Maps by Configuration and Goal

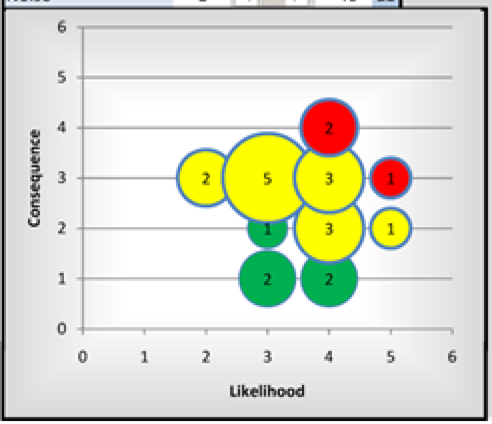
SUGAR High

SUGAR High - Equal Goal Weighting

BOEING

Concept
SUGAR High

NASA Goals			
Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	1	-70	%
NoX	1	-75	%
Noise	1	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	TAPS & Next Generation TAPS					
2	Low sulfur Jet-A, Synthetic or Biofuels					
3	NextGen ATM Capable					
4	Additional advanced passive treatments					
5	Natural Laminar Flow					
6	Very high bypass ratio turbofan with 2030 engine technologies					
7	Low Drag Strut (no interference, laminar flow in NLF)					
8	Very high bypass ratio turbofan with advanced engine tech.					
9	Bundle together advanced engine materials					
10	Bundle together advanced material technologies					
11	Advanced Supercritical Airfoil					
12	Active noise control/fluidics					
13	Fuselage & Wing Riblets					
14	Bundle together advanced subsystem technologies					
15	Active/Passive Aeroelastic Response for Load Control					
16	Adv. Lightweight High Lift Systems					
17	Bundle together multi-functional structures technologies					
18	Relaxed Static Stability & Increased CLMax Empennage					
19	Low Interference Nacelles					
20	Airframe acoustic technologies					
21	Bundle together advanced structures technologies					
22	Lightweight Wing Folds					
23						
24						
25						
26						

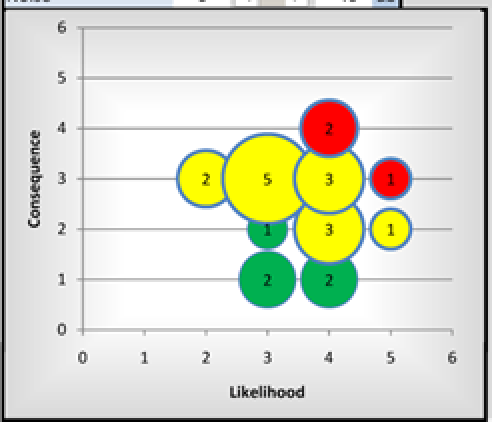
Figure 7.8 – SUGAR High Technology Ranking with Equal Goal Weighting

SUGAR High - Cruise Emissions Goal

Concept
SUGAR High

NASA Goals

Goal	Importance	Value	
Fuel Burn	0	-70	%
Cruise Emissions	1	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	Low sulfur Jet-A, Synthetic or Biofuels					
2	NextGen ATM Capable					
3	Natural Laminar Flow					
4	Very high bypass ratio turbofan with 2030 engine technologies					
5	Low Drag Strut (no interference, laminar flow in NLF)					
6	Very high bypass ratio turbofan with advanced engine tech.					
7	Bundle together advanced engine materials					
8	Bundle together advanced material technologies					
9	Advanced Supercritical Airfoil					
10	Fuselage & Wing Riblets					
11	Bundle together advanced subsystem technologies					
12	Active/Passive Aeroelastic Response for Load Control					
13	Adv. Lightweight High Lift Systems					
14	Bundle together multi-functional structures technologies					
15	Relaxed Static Stability & Increased CLMax Empennage					
16	Low Interference Nacelles					
17						
18	Bundle together advanced structures technologies					
19	Additional advanced passive treatments					
20	Airframe acoustic technologies					
21	Active noise control/fluidics					
22	Lightweight Wing Folds					
23						
24						
25						
26						

Figure 7.10 – SUGAR High Technology Ranking for Cruise Emissions Goal

Risk Maps by Configuration and Goal

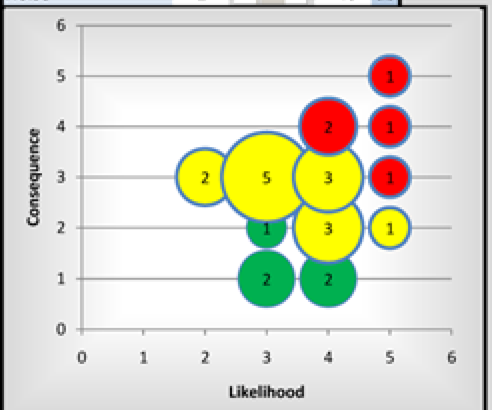
SUGAR Volt

SUGAR Volt - Equal Goal Weighting

BOEING

Concept
SUGAR Volt

NASA Goals			
Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	1	-70	%
NoX	1	-75	%
Noise	1	-40	db



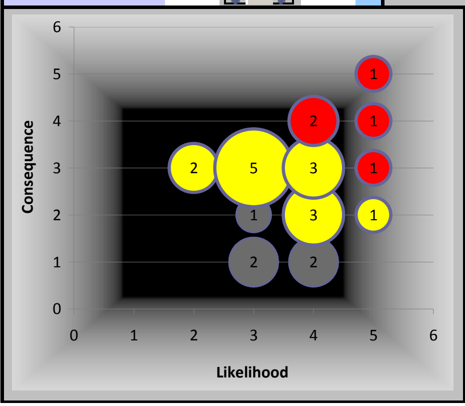
Rank	Technology	Score	Fuel Burn	Cruise Emm.	Nox	Noise
		Contribution to NASA Goal				
1	Battery Gas Turbine Hybrid (SUGAR High tech level)					
2	TAPS & Next Generation TAPS					
3	Low sulfur Jet-A, Synthetic or Biofuels					
4	NextGen ATM Capable					
5	Additional advanced passive treatments					
6	Natural Laminar Flow					
7	Very high bypass ratio turbofan with 2030 engine technologies					
8	High Performance Modular Batteries					
9	Low Drag Strut (no interference, laminar flow in NLF)					
10	Bundle together advanced engine materials					
11	Bundle together advanced material technologies					
12	Advanced Supercritical Airfoil					
13	Active noise control/fluidics					
14	Very high bypass ratio turbofan with advanced engine tech.					
15	Fuselage & Wing Riblets					
16	Bundle together advanced subsystem technologies					
17	Active/Passive Aeroelastic Response for Load Control					
18	Adv. Lightweight High Lift Systems					
19	Bundle together multi-functional structures technologies					
20	Relaxed Static Stability & Increased CLMax Empennage					
21	Low Interference Nacelles					
22	Airframe acoustic technologies					
23	Bundle together advanced structures technologies					
24	Lightweight Wing Folds					
25						
26						

Figure 7.13 – SUGAR Volt Technology Ranking with Equal Goal Weighting

SUGAR Volt - Fuel Burn Goal

Concept
SUGAR Volt

NASA Goals			
Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	0	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Δ	Technology	Score	Fuel Burn	Cruise Emm.	Nox	Noise
			Contribution to NASA Goal				
1	-3	NextGen ATM Capable					
2	-4	Natural Laminar Flow					
3	-4	Very high bypass ratio turbofan with 2030 engine technologies					
4	3	Battery Gas Turbine Hybrid (SUGAR High tech level)					
5	-3	High Performance Modular Batteries					
6	-3	Low Drag Strut (no interference, laminar flow in NLF)					
7	-3	Bundle together advanced engine materials					
8	-3	Bundle together advanced material technologies					
9	-3	Advanced Supercritical Airfoil					
10	-4	Very high bypass ratio turbofan with advanced engine tech.					
11	-4	Fuselage & Wing Riblets					
12	-4	Bundle together advanced subsystem technologies					
13	-4	Active/Passive Aeroelastic Response for Load Control					
14	-4	Adv. Lightweight High Lift Systems					
15	-4	Bundle together multi-functional structures technologies					
16	-4	Relaxed Static Stability & Increased CLMax Empennage					
17	-4	Low Interference Nacelles					
18	16						
19	16						
20	-3	Bundle together advanced structures technologies					
21	16	Additional advanced passive treatments					
22	0	Airframe acoustic technologies					
23	10	Active noise control/fluidics					
24	0	Lightweight Wing Folds					
25	0						
26	0						

Figure 7.14 – SUGAR Volt Technology Ranking for Fuel Burn Goal

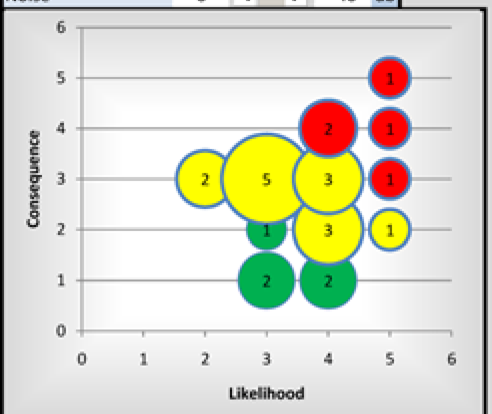
SUGAR Volt - Cruise Emissions Goal

BOEING

Concept
SUGAR Volt

NASA Goals

Goal	Importance	Value	
Fuel Burn	0	-70	%
Cruise Emissions	1	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	Low sulfur Jet-A, Synthetic or Biofuels					
2	NextGen ATM Capable					
3	Natural Laminar Flow					
4	Very high bypass ratio turbofan with 2030 engine technologies					
5	Battery Gas Turbine Hybrid (SUGAR High tech level)					
6	High Performance Modular Batteries					
7	Low Drag Strut (no interference, laminar flow in NLF)					
8	Bundle together advanced engine materials					
9	Bundle together advanced material technologies					
10	Advanced Supercritical Airfoil					
11	Very high bypass ratio turbofan with advanced engine tech.					
12	Fuselage & Wing Riblets					
13	Bundle together advanced subsystem technologies					
14	Active/Passive Aeroelastic Response for Load Control					
15	Adv. Lightweight High Lift Systems					
16	Bundle together multi-functional structures technologies					
17	Relaxed Static Stability & Increased CLMax Empennage					
18	Low Interference Nacelles					
19						
20	Bundle together advanced structures technologies					
21	Additional advanced passive treatments					
22	Airframe acoustic technologies					
23	Active noise control/fluidics					
24	Lightweight Wing Folds					
25						
26						

Figure 7.15 – SUGAR Volt Technology Ranking for Cruise Emissions Goal

SUGAR Volt Tech Ranking for NOx Reduction

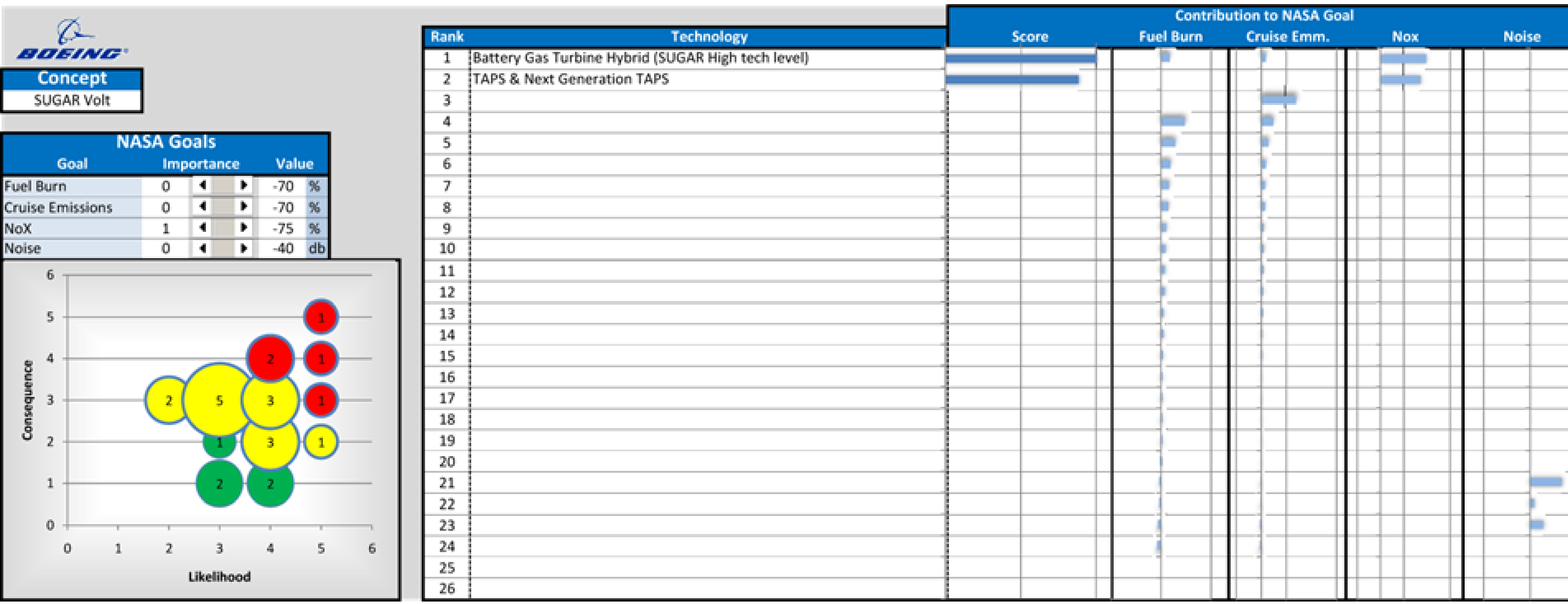


Figure 7.16 – SUGAR Volt Technology Ranking for NOx Reduction Goal

Risk Maps by Configuration and Goal

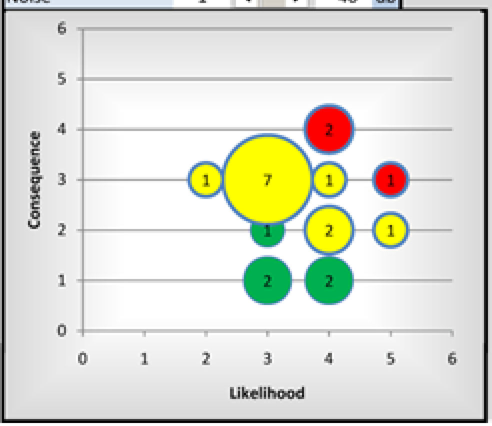
SUGAR Ray

SUGAR Ray - Equal Goal Weighting

Concept
SUGAR Ray

NASA Goals

Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	1	-70	%
NoX	1	-75	%
Noise	1	-40	db



Rank	Technology
1	TAPS & Next Generation TAPS
2	Low sulfur Jet-A, Synthetic or Biofuels
3	NextGen ATM Capable
4	Airframe Noise Shielding
5	Additional advanced passive treatments
6	Very high bypass ratio turbofan with advanced engine tech.
7	Natural Laminar Flow
8	Very high bypass ratio turbofan with 2030 engine technologies
9	Active noise control/fluidics
10	Bundle together advanced engine materials
11	Fuselage & Wing Riblets
12	Bundle together advanced material technologies
13	Airframe acoustic technologies
14	Open Fan
15	Active/Passive Aeroelastic Response for Load Control
16	Low Interference Nacelles
17	Relaxed Static Stability & Increased CLMax Empennage
18	Bundle together multi-functional structures technologies
19	Bundle together advanced structures technologies
20	Lightweight Wing Folds
21	
22	
23	
24	
25	
26	

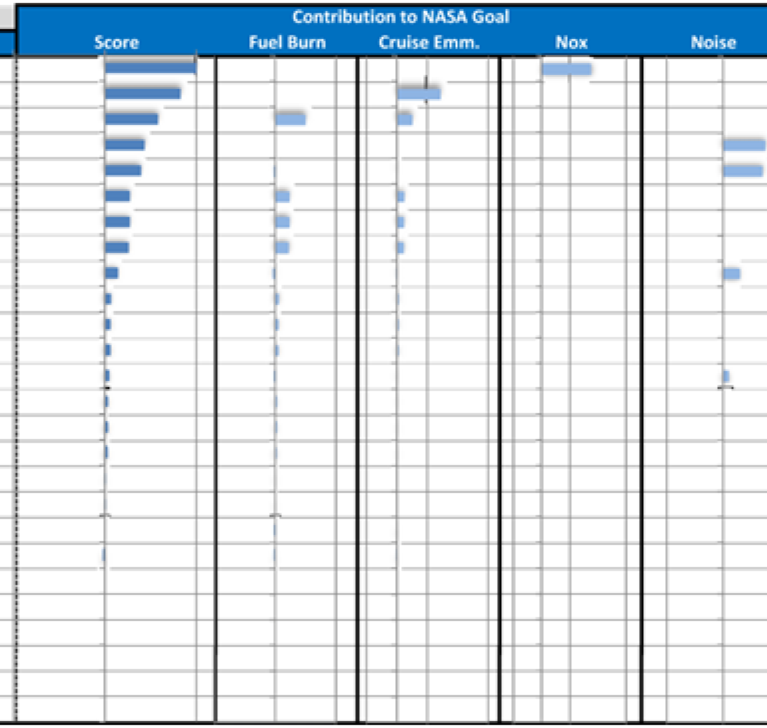
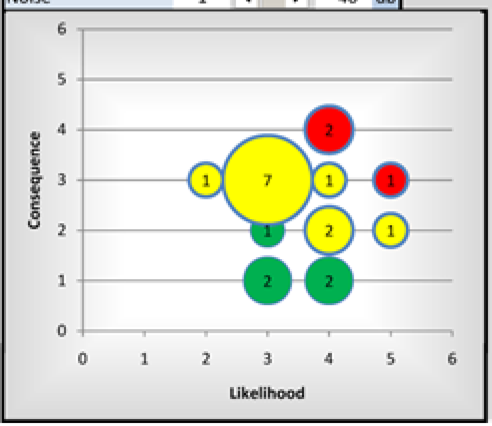


Figure 7.18 – SUGAR Ray Technology Ranking with Equal Goal Weighting

SUGAR Ray - Noise Reduction Goal

Concept
SUGAR Ray

NASA Goals			
Goal	Importance	Value	
Fuel Burn	0	-70	%
Cruise Emissions	0	-70	%
NoX	0	-75	%
Noise	1	-40	db



Rank	Technology	Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	Airframe Noise Shielding					
2	Additional advanced passive treatments					
3	Active noise control/fluidics					
4	Airframe acoustic technologies					
5						
6						
7						
8						
9						
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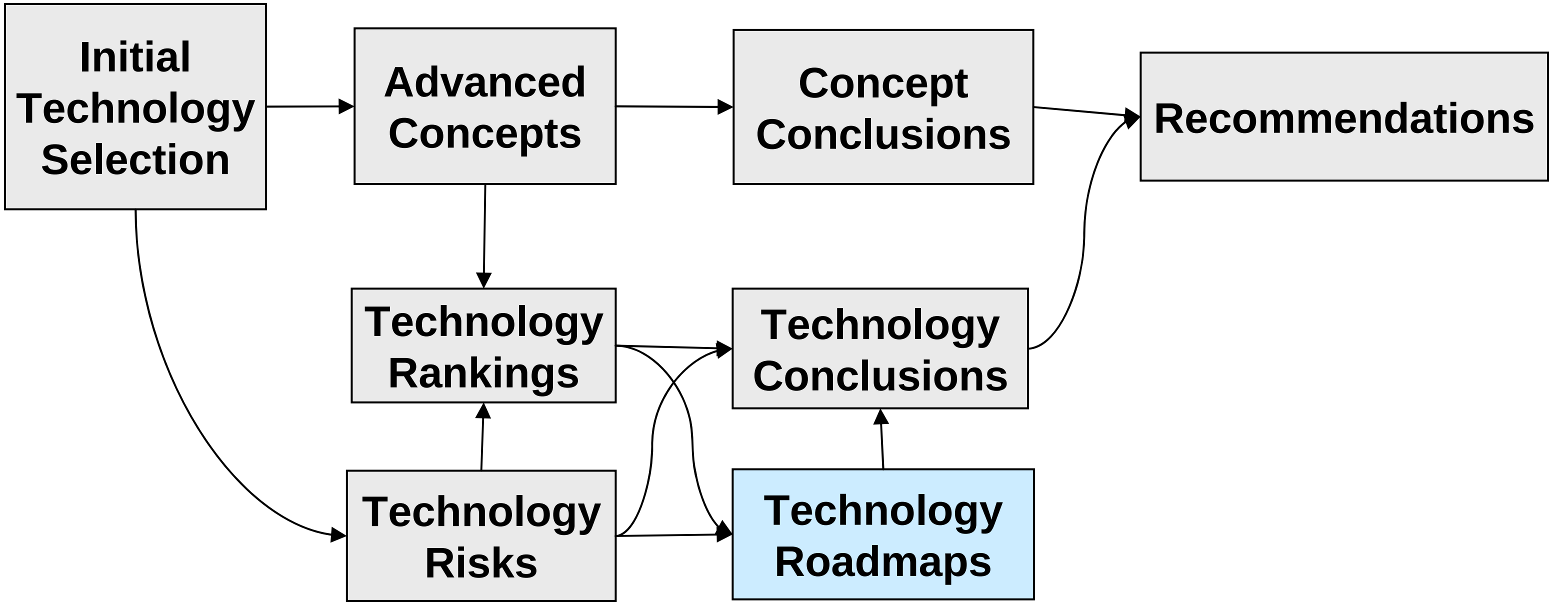
Figure 7.22 – SUGAR Ray Technology Ranking for Noise Reduction Goal

Technology Ranking Summary

Ranking	Technology or Technology Group	Goals
Game-Changing	Hybrid Electric Propulsion & High Performance Modular Batteries	Noise, Emissions, Fuel Burn, TOFL
Critical	Advanced Combustors	Emissions
Critical	Biofuels	Emissions
Critical	NextGen ATM	Emissions, Fuel Burn
Critical	Engine Noise Treatments	Noise
Critical	Aero Technologies (Inc. Laminar Flow)	Noise, Emissions, Fuel Burn, TOFL
Important	Engine Technologies	Fuel Burn
Important	Airframe Acoustic Technologies	Noise
Important	Airframe Materials & Structures	Fuel Burn
Important	Advanced Subsystems	Emissions, Fuel Burn

SUGAR Phase 1 Process



Roadmaps for High Leverage Technologies

Hybrid Engine Technology

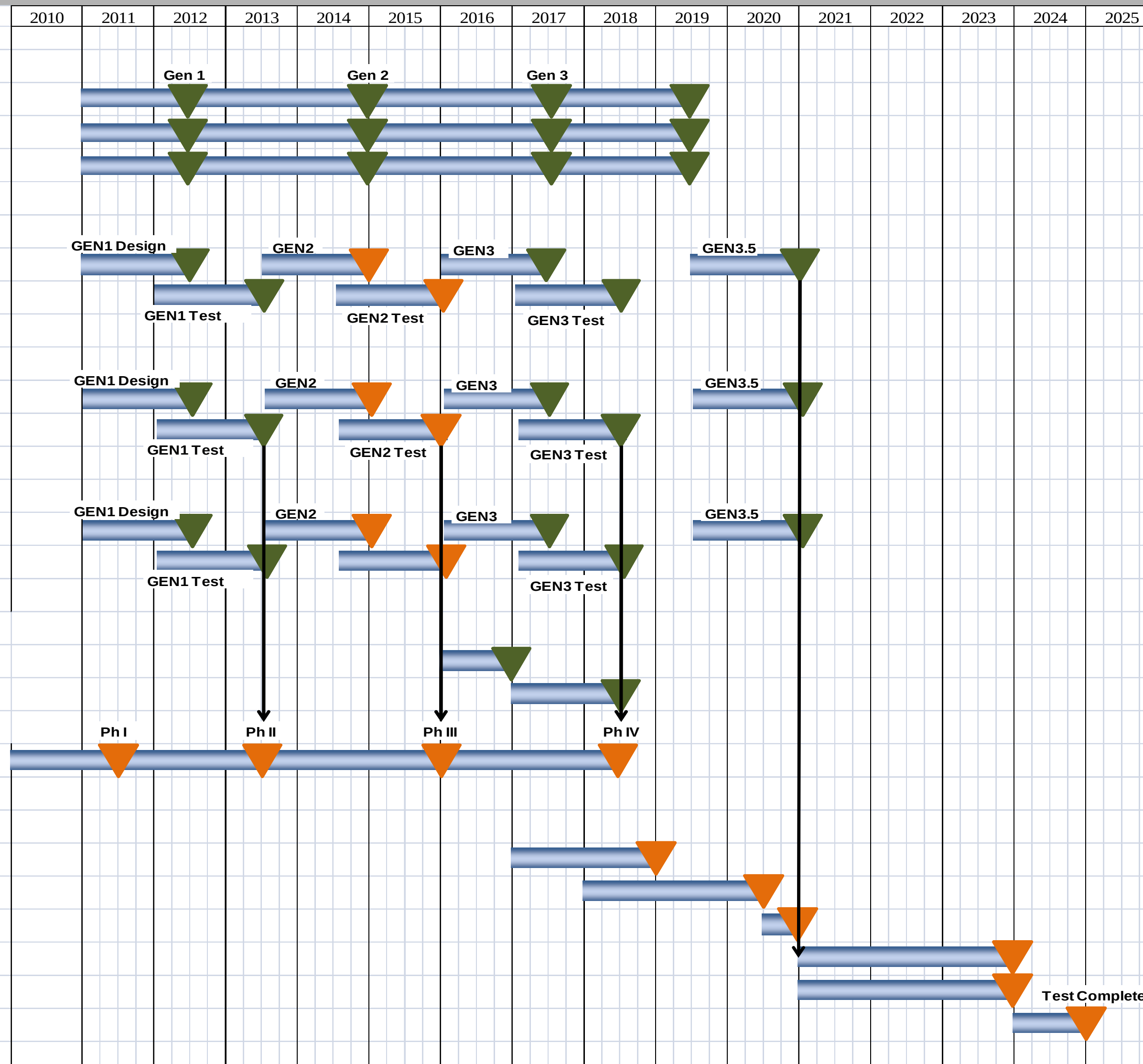
Hybrid Engine Technologies

- **Goals and Objectives:**
  - Develop high performance, flight weight, prime-reliable electric power components suitable for flight propulsion applications.
- **Performance Area and Impact:**
  - Noise, Fuel burn, Emissions
- **Technical Description:**
  - Develop high power, light weight motors, controllers, radiators and surface coolers, variable core nozzle

Hybrid Engine Technologies Roadmap

BCA – Advanced Concepts | BR&T – Platform Performance Technology

TRL	Task	
	1	Lightweight flightworthy high voltage enabling materials
3	1.1	Insulor Materials Program
3	1.2	Conductors and Connectors Program
3	1.3	Lightweight Magnetics & Support Structure
2-3-4	2	Flight weight, prime-reliabel motor
	2.1	Design Modeling & Analysis
	2.2	Controller Fabrication & Bench Test
2-3-4	3	Motor Controller/Power Electronics
	3.1	Design Modeling & Analysis
	3.2	Controller Fabrication & Bench Test
2-3-4	4	Light weight, low loss cooler/radiator
	4.2	Design Modeling & Analysis
	4.3	Design Fabrication & Bench Test
2-3-4	5	Variable Core Nozzle
	5.1	Design Modeling & Analysis
	5.2	Nozzle Fabrication & Component Tests
	6	Engine Design Studies
	7	Full Scale Demo
	7.1	Demo Engine Design & Integration
	7.2	Demo Build 1 Component Fabrication & Assembly
5	7.3	Demo Build 1 Test
	7.4	Demo Build 2 Design & Integration
	7.5	Demo Build 2 Component Fabrication & Assembly
6	7.6	Demo Build 2 Test



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Roadmaps for High Leverage Technologies

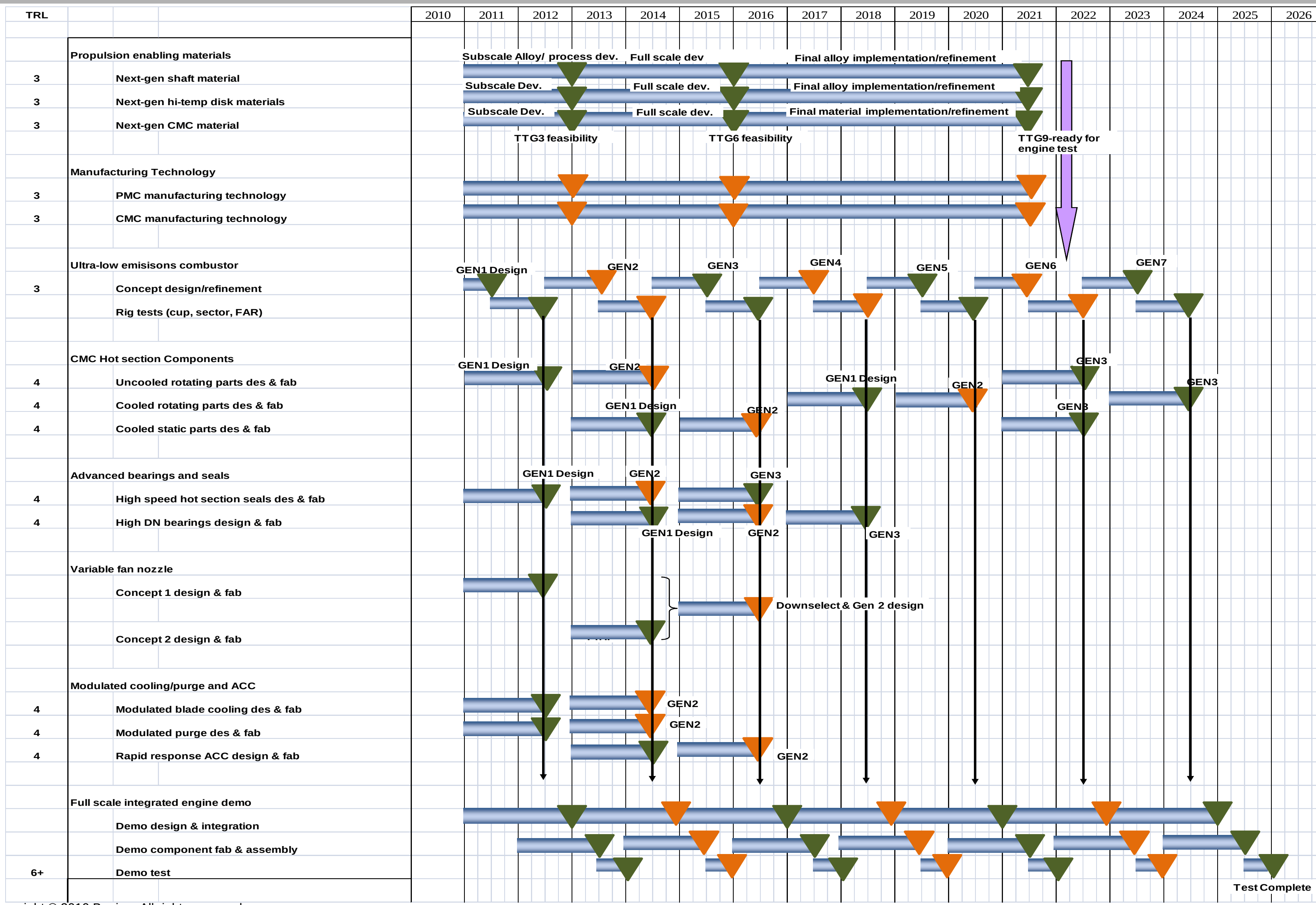
Advanced Engine Technology

Advanced Engine Technologies

- **Goals and Objectives:**
  - Develop enabling materials and methods for improved component performance
- **Performance Area and Impact:**
  - Noise, Fuel burn, Emissions
- **Technical Description:**
  - Develop propulsion enabling materials, cooling technology and component technology to support continued advancements in gas turbine efficiency, weight, and power

Advanced Engine Technologies Roadmap

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**



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Roadmaps for High Leverage Technologies

Alternative Fuels

Alternative Fuels

- **Goals and Objectives:**
    - Develop drop-in replacement alternative fuels with comparable performance to conventional fuel and lower life cycle GHG and airport emissions
- **Performance Area and Impact:**
    - LTO NOx
        - Small to Medium Reduction
    - Cruise Emissions
        - Substantial Reduction (for biofuels)
- **Technical Description:**
    - Fuel Testing (Engine & fuel system components)
    - Life Cycle Assessment
    - Emissions Testing
    - Fuel Testing (Engine System)
    - Certification Documentation
    - System Changes for Near Drop-In fuels (Alternate)
    - Certification of Engine and Aircraft Systems for Near Drop-In fuels (Alternate)
    - Low Sulfur Jet-A Implementation (Alternate)

Alternative Fuels Success Criteria

Task Number	Task Name	Success Criteria	Alternate Steps if Unsuccessful
1	**Fuel Testing (Engine & fuel system components)**	Comparable performance and compatibility with existing fuel and engine systems	Reduce blend % or initiate modification of systems (Task 6 & 7)
2	**Life Cycle Assessment**	Verifiable reduction in lifecycle GHG at competitive cost	Choose sustainable feedstock and processes. Ultimate fall back is to continue to use fossil fuels
3	**Emissions Testing**	Emissions better than existing fuels.	Fall back to conventional fuels (Task 8)
4	**Fuel Testing (Engine System)**	Comparable performance and compatibility with existing and future engines	Reduce blend % or initiate modification of systems (Task 6 & 7)
5	**Certification Documentation**	Research report and ballot	Additional testing or analysis to resolve issues
6	**System Changes for Near Drop-In fuels (Alternate)**	Compatible system design for near drop-in fuels	Fall back to conventional fuels (Task 8)
7	**Certification of Engine and Aircraft Systems for Near Drop-In fuels (Alternate)**	Verification of compatibility and performance assumptions	Fall back to conventional fuels (Task 8)
8	**Low Sulfur Jet-A Implementation (Alternate)**	Verification of compatibility and emissions performance	
9	**Feedstock Technologies**		
10	**Production Technologies**		

Table 7.6 – Alternative Fuels Success Criteria

Alternative Fuels Roadmap

BCA – Advanced Concepts | BR&T – Platform Performance Technology

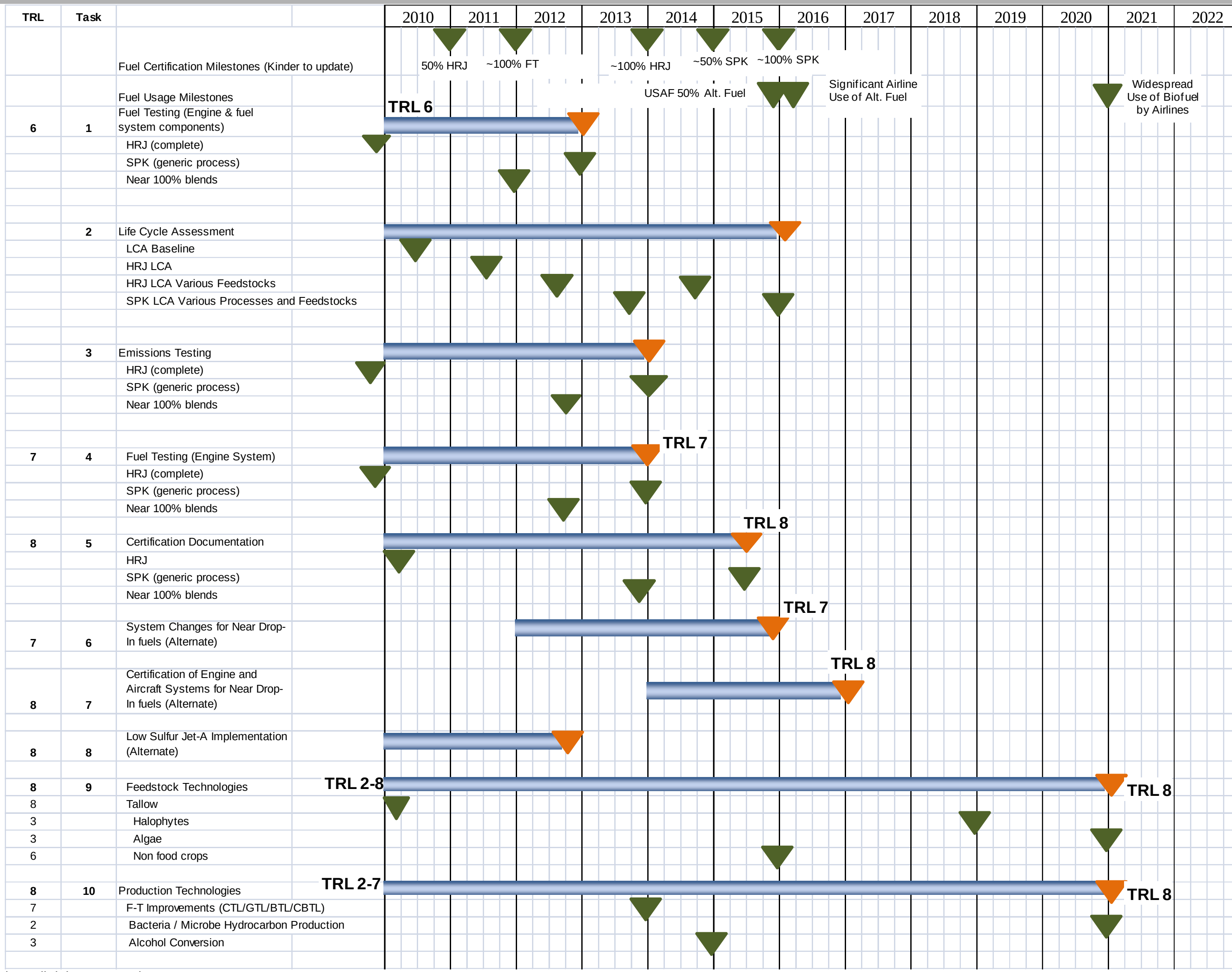


Figure 7.35 – Alternative Fuels Roadmap

Roadmaps for High Leverage Technologies

Next Generation ATM

Next Generation Air Traffic Management

- **Goals and Objectives:**
  - Integrate avionics components into the aircraft in order to make it compatible with the Next Generation Air Transportation System (NextGen). Increase capacity, reduce delays, and improve safety throughout the ATS through technological improvements both on the ground and in the air.
- **Performance Area and Impact:**
  - LTO NOx
    - Substantial Reduction (reduced taxi time)
  - Fuel Burn
    - Substantial Reduction (17% for current technology vehicles)
  - Cruise Emissions
    - Substantial Reduction (17% for current technology vehicles)
  - System Capacity
    - Substantial Increase (increased capacity at airport and increase airports)
- **Technical Description:**
  - NextGEN encompasses all the aircraft and ground related improvements that must be accomplished in order to realize the benefits to fuel efficiency, capacity and safety.
  - Limited to the on-aircraft components only for this study

Next Generation ATM Success Criteria

Task Number	Task Name	Success Criteria	Alternate Steps if Unsuccessful
1	**Communications**	Aircraft and ground controllers can share information and voice communications simultaneously	Current SoA
2	**Navigation**	Ability of the controller to accurately predict and control the location of aircraft at any point in the flight profile	Current SoA
3	**Collision Avoidance**		
4	**Weather Capability**	Aircraft-Aircraft weather detection and information sharing	Current SoA
5	**Wake Vortex Detection**	Aircraft wake prediction based off type of aircraft and atmospheric conditions allows for decreased separation distance	Current SoA
6	**Synthetic Vision**		

Next Generation ATM Operational Roadmap

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

IRL	Task	
3	1	**Communications**
		Avionics - Delegated Separation Digital Communications
		Integrated Ground and Air Network for Voice/Data
5	2	**Navigation**
		Trajectory Negotiation - Level 1 CTA
		Trajectory Negotiation - Level 2 En-Route Time-Based Metering
		Trajectory Negotiation - Level 3 Automation-Assisted 4DTs
		Trajectory Negotiation - Level 4 Automated 4DTs
6	3	**Collision Avoidance**
		Airborne Collision Avoidance - Level 2
		Airborne Collision Avoidance - Level 3
		Airborne Collision Avoidance - Level 4
5	4	**Weather Capability**
		Aircraft-Aircraft Hazardous Weather Information Sharing
6	5	**Wake Vortex Detection**
		Parameter Driven Aircraft Separation Standards and Procedures
		Wake Detection/Prediction w/Dynamic Wake Spacing - Level 1 Wake Drift
		Wake Detection/Prediction w/Dynamic Wake Spacing - Level 1 Wake Drift
5	6	**Synthetic Vision**
		Synthetic Vision Systems - Level 2
		Enhanced Vision Systems - Level 3

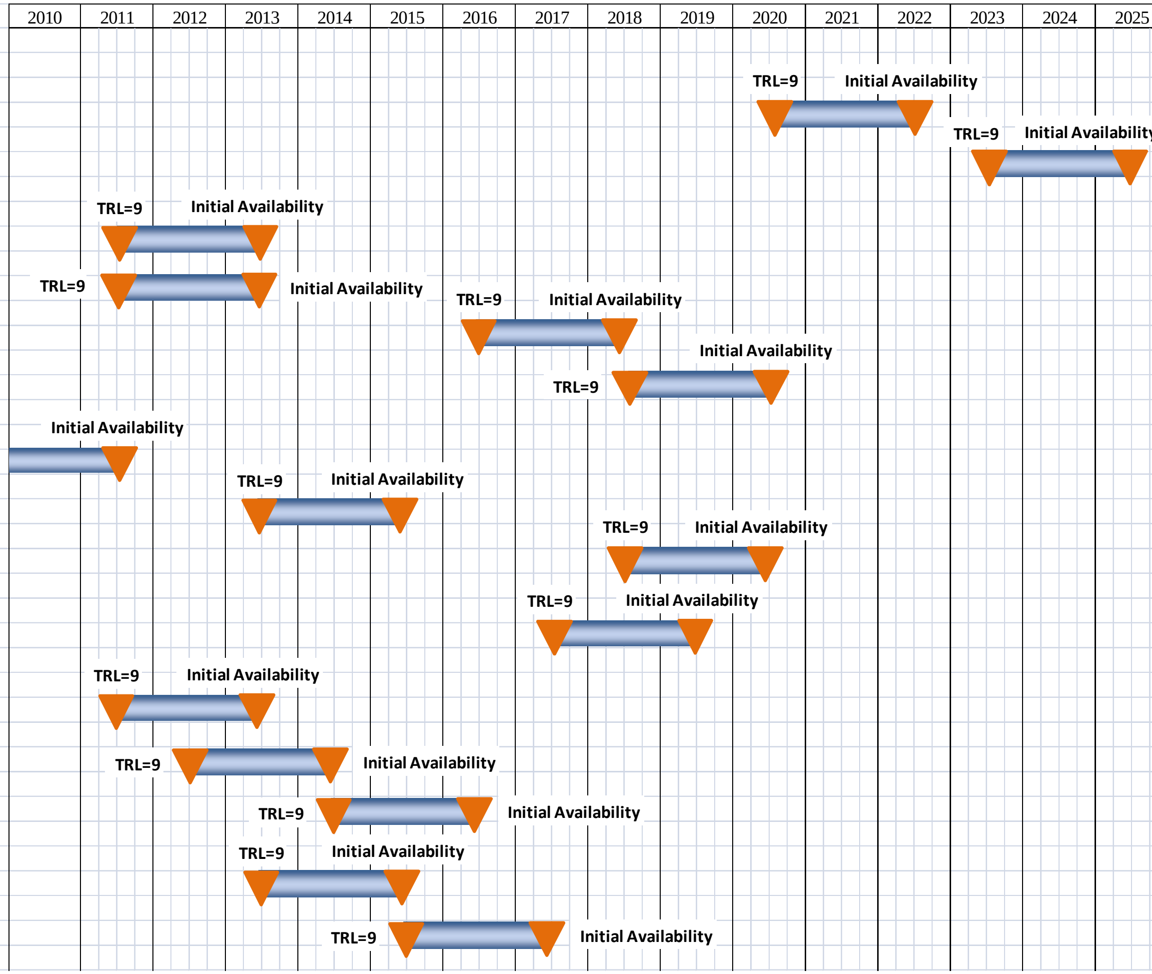


Figure 7.33 – Next Generation Air Traffic Management Operational Roadmap

Next Generation ATM Technical Roadmap

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

TRL	Task	
	1	**Communications**
		Applied Research on Integrated Voice/Data and Air/Ground Network Communications
	2	**Navigation**
6		Applied Research on 3D RNAV/RNP Procedures
5		Applied Research on a Low Cost INS
4		Applied Research on Required Aircraft 4D Intent Data
	4	**Weather Capability**
6		Enhanced Airborne Based Weather Sensors
	5	**Wake Vortex Detection**
6		Dynamic Wake Management for Single Runway Operation
6		Advanced Wake Sensing Capabilities

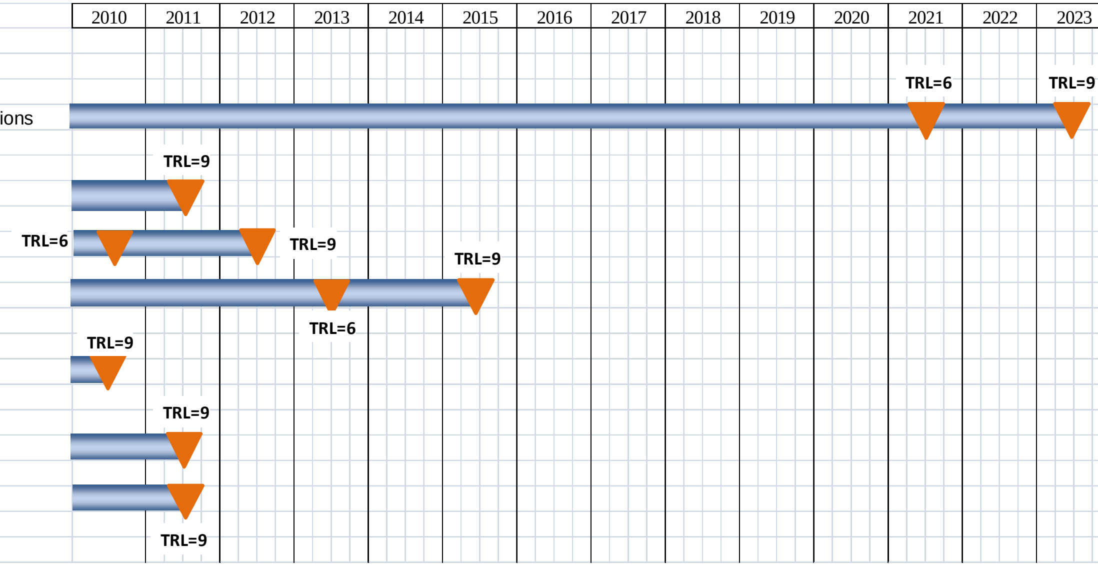


Figure 7.34 – Next Generation Air Traffic Management Technical Roadmap

Roadmaps for High Leverage Technologies

Engine Acoustics

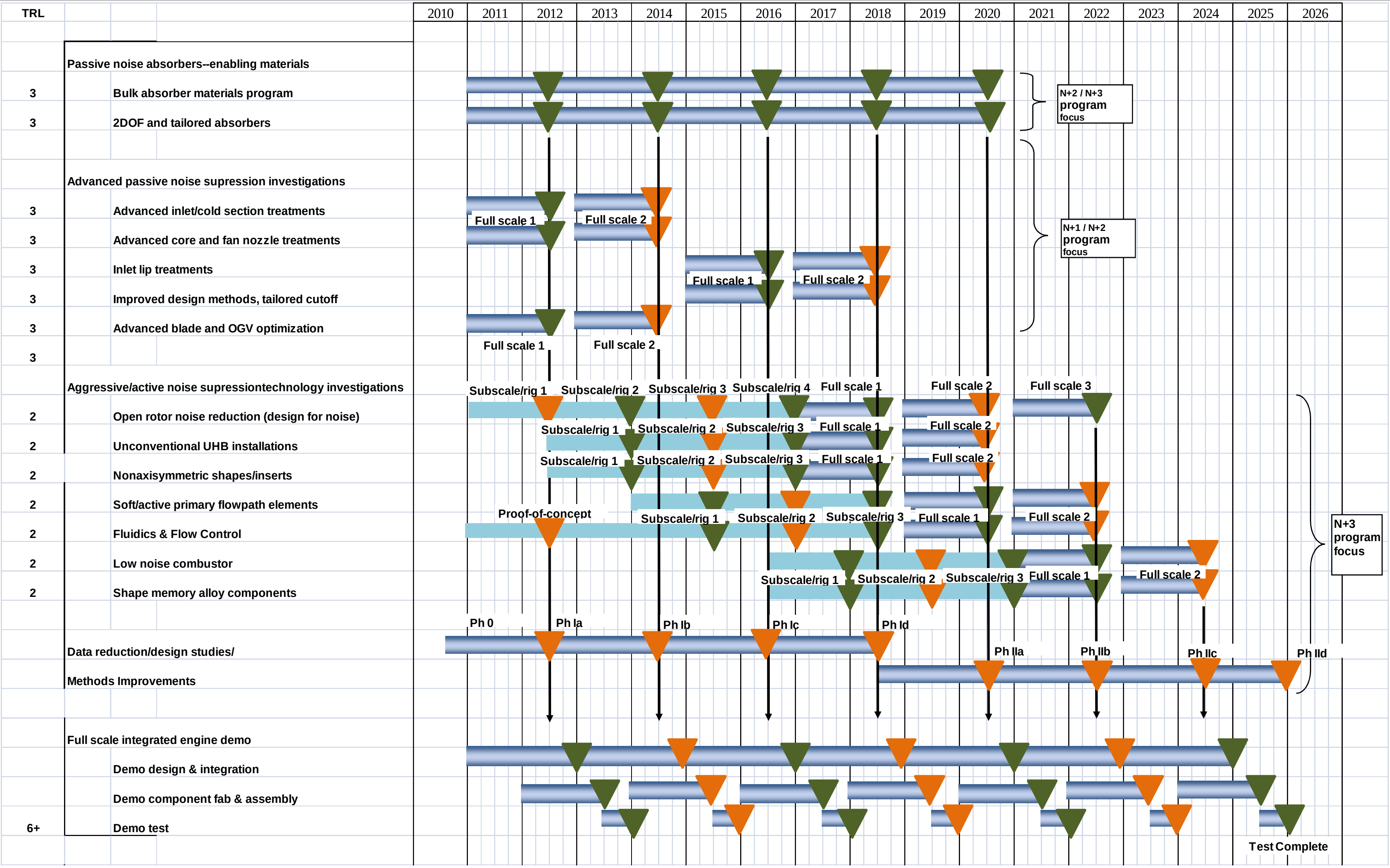
Engine Acoustic Technologies

- **Goals and Objectives:**
  - Develop new and innovative designs and methods to reduce propulsion system noise
- **Performance Area and Impact:**
  - Engine Acoustic Properties
- **Technical Description:**
  - Two pronged approach to develop a suite of near-term, mostly passive technologies and far-term aggressive suppression technologies

Engine Acoustic Technology Roadmap

BCA – Advanced Concepts

BR&T – Platform Performance Technology



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Roadmaps for High Leverage Technologies

Aerodynamics

Aerodynamic Technologies

- **Goals and Objectives:**
  - Develop and Implement Aerodynamic Technologies to contribute 30% improvement in fuel efficiency relative to current fleet.
- **Performance Area and Impact:**
  - – Improved Airplane Performance through drag reduction.
- **Technical Description:**
  - – Laminar flow
  - – Riblets
  - – Improve design integration of nacelles in the presence of wings
  - – Improve design integration of Strut braced configuration
  - – Reduced static stability reduces trim drag
  - – Increased CLmax tail designs reduces tail area and weight.
  - – Wing design to accommodate active/passive aeroelastic response for load control. This technology is shared with Structures.

Aero Technologies Success Criteria

BCA – Advanced Concepts | BR&T – Platform Performance Technology

Task Number	Task	Success Criteria	Alternative steps if unsuccessful
1	**Laminar Flow**		
	Passive LFC	NLF laminar design matches Active LFC	Achieve 50% of an Active LFC laminar Run
	Active LFC	Achieve Laminar to shocks with low power consumption	Establish break even points between NLF/Passive/Active
2	**Low Interference Drag Struts**	Integrate strut into wing-body for only strut parasite drag	Establish low interference levels
3	**Advanced Super-Critical Wing**	Target 3% airplane drag improvement while attaining high design lift coefficient	Achieve 50% of target drag improvement
4	**Riblet Integration**	Target 2% - 3% airplane drag improvement	
5	**Low Interference Drag Nacelles**	Integrate nacelle/pylon to wing body for only nacelle/pylon parasite drag	Establish low interference levels
6	**Relaxed static stablity Increased CLmax Empennage**	Achieve neutral static stability to reduce tail size. Improve empennage CLmax to reduce tail size	Demonstrate some reduction in tail size
7	**Aeroelastic Load Control**	Span load traded for Aerodynamics and structural efficiencies to improve overall mission performance	Achieve improvement for one discipline

Table 7.7 – Aerodynamic Technologies Success Criteria

Aerodynamic Technologies Roadmap

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

Figure 7.36 – Aerodynamic Technologies Roadmap

Roadmaps for High Leverage Technologies

Airframe Acoustics

Airframe Acoustic Technologies

- **Goals and Objectives:**
  - Develop airplane designs and technologies that reduce airframe noise and increase shielding of engine noise, in order to meet future strict noise regulations in airport environments
- **Performance Area and Impact:**
  - Engine noise dominance at take-off (cutback and sideline), and airframe noise dominance at approach.
  - Impact on Aerodynamics, Propulsion, and Airframe Design
- **Technical Description:**
  - Develop inherently quiet landing gear designs (includes main and nose gear)
  - Develop inherently quiet high-lift system designs
  - Develop integrated engine-airframe designs with inherent shielding
  - Develop technologies to reduce landing gear, high-lift, jet and aft-fan noise
  - Develop technologies to maximize engine noise shielding
  - Evaluate and down-select design ideas and technology concepts using:
    - (a) acoustics integrated into multidisciplinary design,
    - (b) airframe noise and engine noise shielding testing including model-scale and full-scale flight tests, and
    - (c) development of tools for acoustic design, analysis, and prediction of airframe noise and engine noise shielding

Airframe Acoustic Technologies Success Criteria

Task Name	Success Criteria	Alternate Steps if Unsuccessful
Quiet Landing Gear Design	5 dB reduction in gear noise	More testing with alternate concepts or use of lowest attained reduction level
	Landing Gear design tool	Alternate approach/methodology or use of existing gear noise prediction tools
Advanced Airframe and Engine Design and Integration for Shielding Optimization	5 dB reduction in jet and aft-fan noise	More testing with alternate concepts or use of lowest attained reduction level
	15-20 dB cumulative shielding benefit (sum of jet, inlet, and aft-fan shielding)	More testing with alternate concepts or use of highest attained shielding benefit
	Shielding design tool	Alternate approach/methodology or use of existing shielding prediction tools
Advanced Acoustic Design for High-Lift Systems	8-10 dB combined reduction	Use of lowest existing high-lift noise levels
	High-Lift System design tool	Use of existing noise prediction tools
Full-Scale Flight Testing for Validation and Assessment of TRL8	Agreement between model-scale and full-scale results; realizing most of the expected benefits	Adjustment/extrapolation of existing data
		Conservative use of model-scale benefits

Table 7.8 – Airframe Acoustic Technologies Success Criteria

Airframe Acoustic Technology Roadmap 1/2

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

TRL	Task	
3	1	**Quiet Landing Gear Design**
		Includes: main gear and nose gear
		1a) Steady State CFD
		1b) Selection of promising airframe designs and technology concepts for model-scale testing
		1c) Model-scale gear noise testing
		1d) Database of results from model-scale gear noise testing
		1e) Guidelines for inherently quiet landing gear design
		1f) Development of Landing Gear tool
		1g) Landing Gear Tool for acoustic design, analysis, and prediction
2 - 5	2	**Advanced Airframe and Engine Design and Integration for Shielding Optimization**
		Includes: jet, inlet, and aft-fan
		2a) Integrated aero/acoustic parametric evaluation
		2b) Selection of promising airframe designs and technology concepts for model-scale testing
		2c) Model-scale integrated shielding and jet noise testing
		2d) Model-scale integrated shielding and inlet and aft-fan noise testing
		2e) Database of results from model-scale integrated shielding and jet noise testing, and model-scale integrated shielding and inlet and aft-fan noise testing
		2f) Guidelines for integrated engine-airframe designs with inherent shielding
		2g) Shielding tool development
		2h) Shielding Tool for acoustic design, analysis, and prediction
2	3	**Advanced Acoustic Design for High-Lift Systems**
		Includes: leading and trailing edge devices, and wing trailing edge
		3a) Integrated aero/acoustic optimization
		3b) Selection of promising airframe designs and technology concepts for model-scale testing
		3c) Model-scale high-lift system noise testing
		3d) Database of results from model-scale high-lift system noise testing
		3e) Guidelines for inherently quiet high-lift system design
		3f) High-Lift system design tool development
		3g) High-Lift System Tool for acoustic design, analysis, and prediction

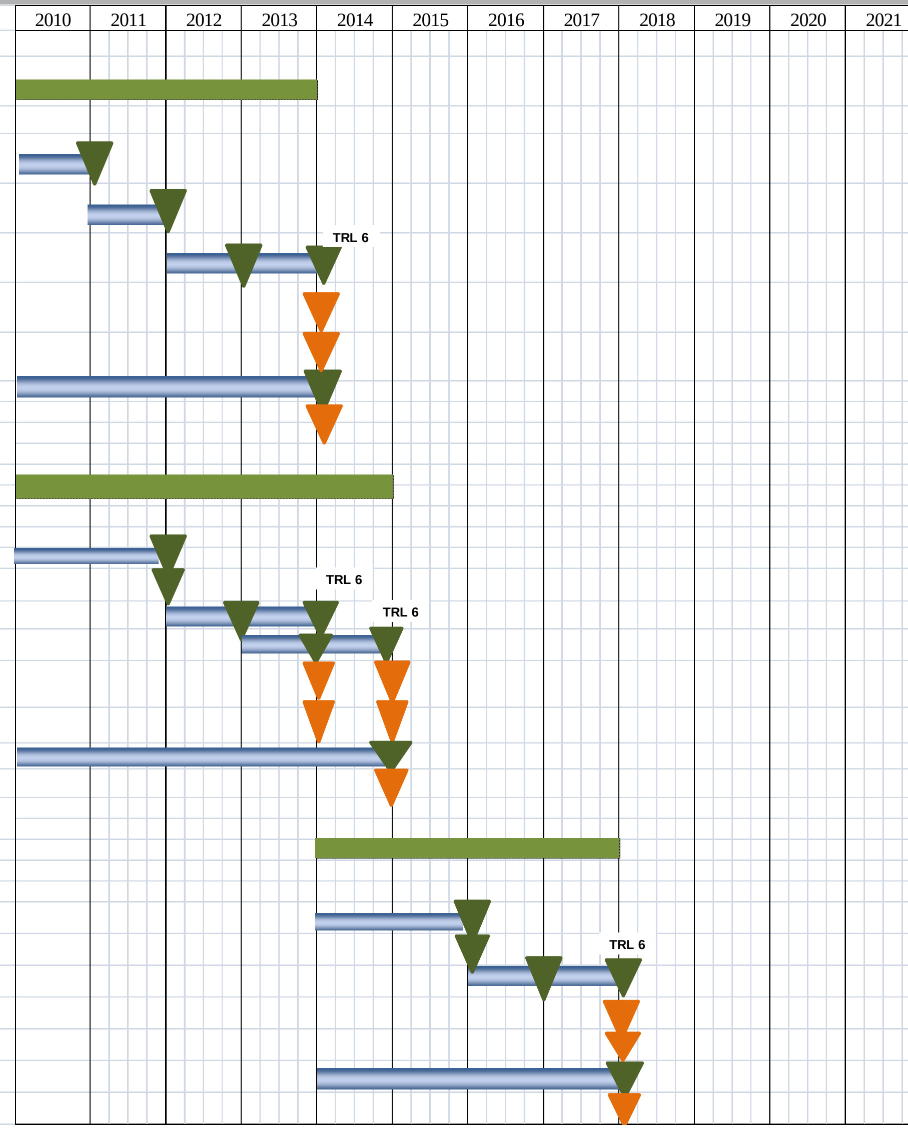

Figure 7.37 – Airframe Acoustic Technology Roadmap (part 1 of 2)

Airframe Acoustic Technology Roadmap 2/2

Figure 7.37 – Airframe Acoustic Technology Roadmap (part 2 of 2)

Roadmaps for High Leverage Technologies

Advanced Subsystems

Advanced Subsystems

- **Goals and Objectives:**
  – Significantly improve weight and reliability of aircraft subsystems
- **Performance Area and Impact:**
  – Reduced airplane weight, improved system reliability
- **Technical Description:**
  – Adaptive Power Management
  – Diesel APU
  – EMA Actuators
  – Fiberoptic Control Architecture
  – Lightweight Thermal Technology
  – Integrated Computing Networks

Advanced Subsystems Success Criteria

Task Number	Task Name	Success Criteria	Alternate Steps if Unsuccessful
1	**Adaptive Power Management**	Certification	Revert to current SOA
2	**Diesel APU**	Certification	Revert to advanced turboshaft APU
3	**EMA Actuators**	Certification	Revert to current SOA
4	**Fiberoptic Control Architecture**	Certification	Revert to current SOA
5	**Lightweight Thermal Technology**	Certification	Revert to current SOA
6	**Integrated Computing Networks - Generation 3.0**	Certification	Revert to current SOA
7	**Integrated Computing Networks - Generation 4.0**	Certification	Revert to generation 3.0 architecture

Table 7.9 – Advanced Subsystems Success Criteria

Advanced Subsystems Roadmap 1/2

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

TRL	Task	
	1	Adaptive Power Management
3	1.1	Intelligent Energy Management Architecture
4	1.2	Adaptive Load Management Models and Simulators
5	1.3	Intelligent components
5	1.4	Self-powered passenger control units
5	1.5	Self-powered wireless sensors
6	1.6	High Power Energy Harvesting
7	1.7	Prototype Testing and Demonstration
8	1.8	Qualification and Certification tests
9	1.9	Flight Ready
	2	Diesel APU
4	2.1	Breadboard demo in sub-atmospheric test chamber
5	2.2	Ground test of prototype scaled unit
6	2.3	Prototype test on the ETD at altitude
7	2.4	Beta unit demonstration
8	2.5	Qualified through certification tests
9	2.6	Flight proven
	3	EMA Actuators
8		Hybrid Control (Conventional EMA)
9		Integrated Flight Demo (Conventional EMA)
6		High Temp Superconducting (HTS) Motor EMA
7		Integrated HTS Based EMA Ground Demo
9		Integrated HTS Based EMA Flight Demo
	4	Fiberoptic Control Architecture
2	4.2	Technology Concept and/or Application formulated
3	4.3	Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept
4	4.4	Component and/or Breadboard Validation in Laboratory Environment
5	4.5	Component and/or Breadboard Validation in Relevant Environment
6	4.6	System/Subsystem Model or Prototype Demonstration in a Relevant Environment
7	4.7	System Prototype Demonstration in Target Environment
8	4.8	System Completed & Flight Qualified through Test and Demonstration
9	4.9	System Flight Proven through Successful Operation

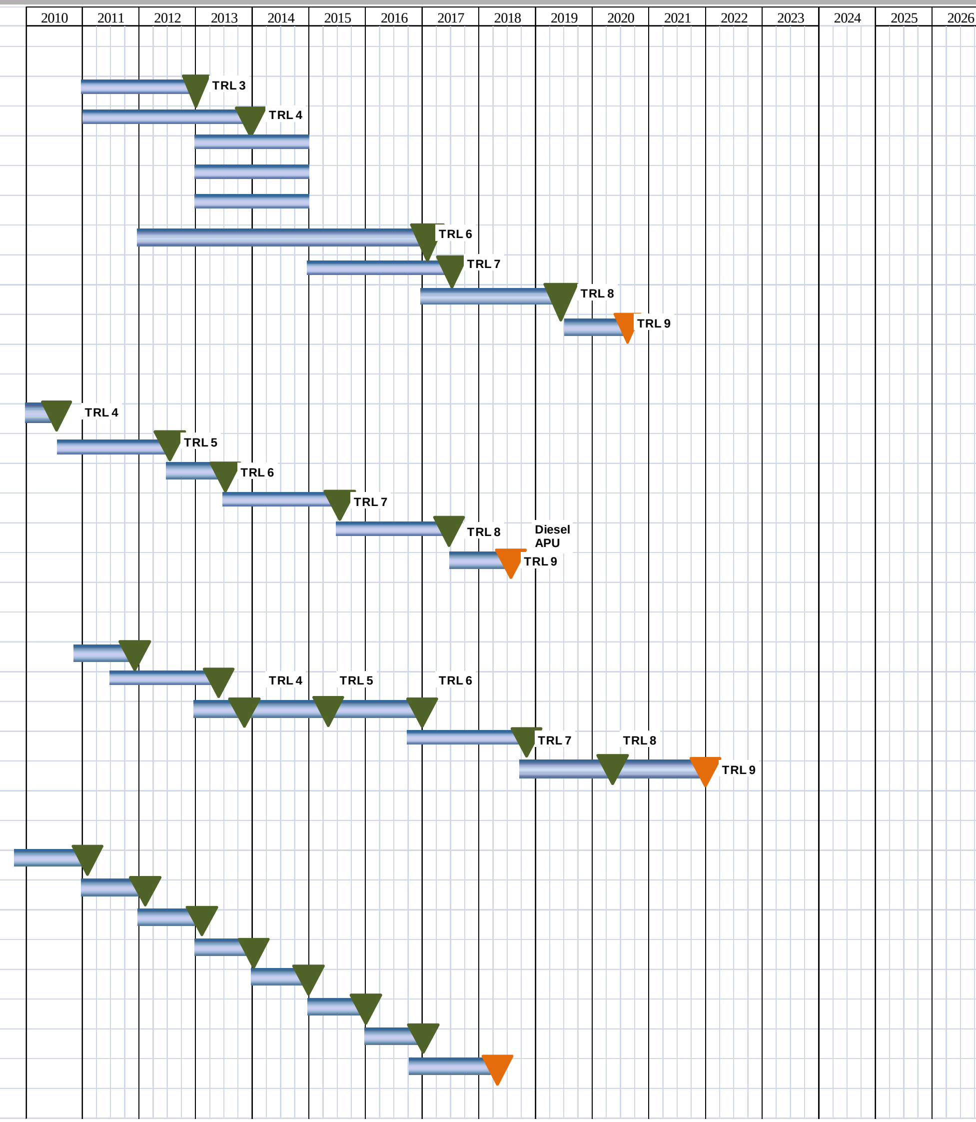

Figure 7.40 – Advanced Subsystems Roadmap (part 1 of 2)

Advanced Subsystems Roadmap 2/2

BCA – Advanced Concepts | **BR&T – Platform Performance Technology**

TRL	Task	
	5	Lightweight Thermal Technology
3	5.1	Integrated Dynamic Models
4	5.2	Total Energy Management Models
5	5.3	Integrated Power /Thermal/EMI Dynamic Models
6	5.4	Total Energy Management Lab Integration
7	5.5	Prototype Testing and Demonstration
8	5.6	Certification
9	5.7	Flight Ready
	6	Integrated Computing Networks -Generation 3.0
4	6.1	Component and/or Breadboard Validation in Laboratory Environment
5	6.2	Component and/or Breadboard Validation in Relevant Environment
6	6.3	System/Subsystem Model or Prototype Demonstration in a Relevant Environment
7	6.4	System Prototype Demonstration in Target Environment
8	6.5	System Completed & Flight Qualified through Test and Demonstration
9	6.6	System Flight Proven through Successful Operation
	7	Integrated Computing Networks -Generation 4.0
2	7.1	Technology Concept and/or Application formulated
3	7.2	Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept
4	7.3	Component and/or Breadboard Validation in Laboratory Environment
5	7.4	Component and/or Breadboard Validation in Relevant Environment
6	7.5	System/Subsystem Model or Prototype Demonstration in a Relevant Environment
7	7.6	System Prototype Demonstration in Target Environment
8	7.7	System Completed & Flight Qualified through Test and Demonstration
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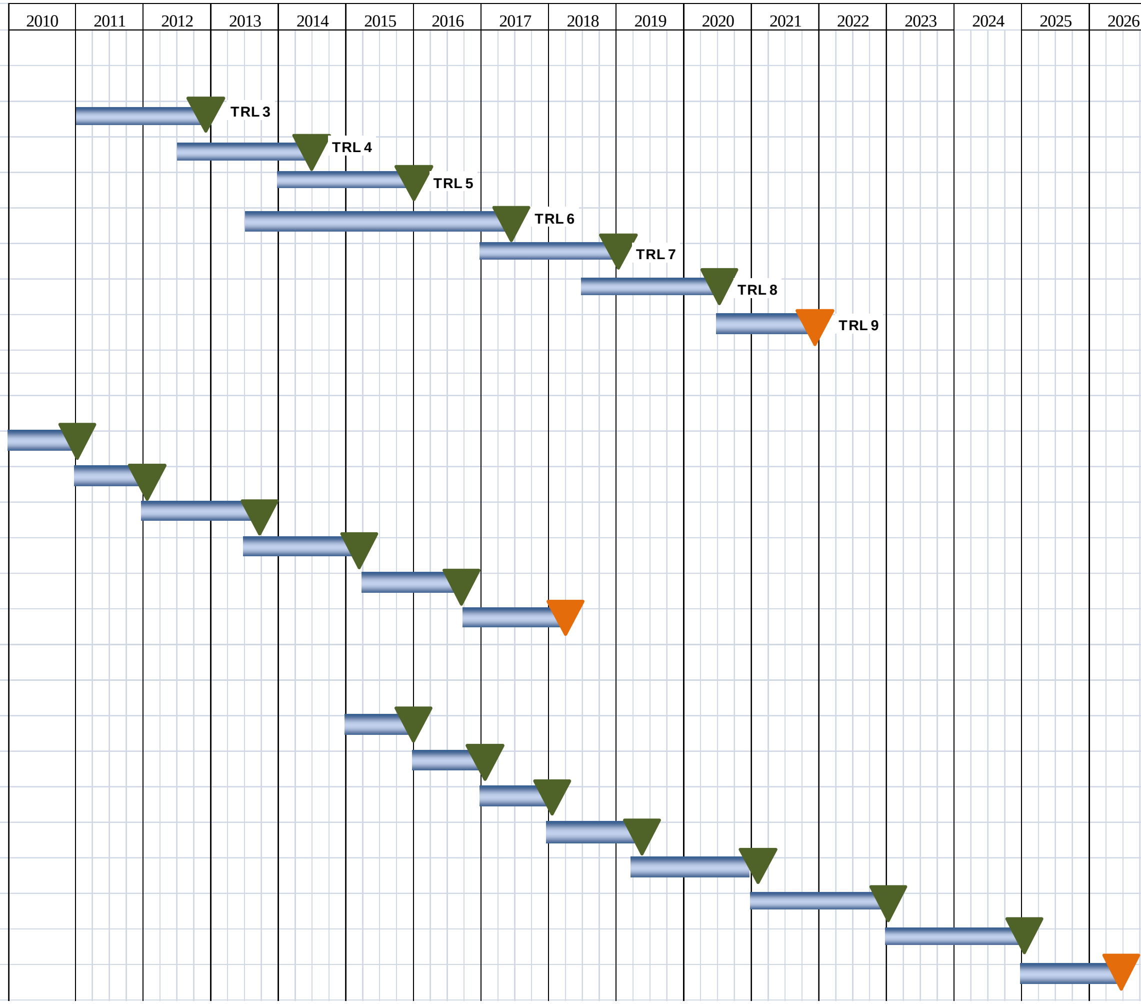


Figure 7.40 – Advanced Subsystems Roadmap (part 2 of 2)

Roadmaps for High Leverage Technologies

Structural Materials

Structural Materials

BCA – Advanced Concepts | BR&T – Platform Performance Technology

- **Goals and Objectives:**
  – Implement advanced materials with greatly improved properties are needed to support the N+3 SUGAR configurations. Improved specific strength and specific stiffness are needed to enable very thin, very high aspect ratio wings.
- **Performance Area and Impact:**
  – Primary, structural weight (OWE).
  – Secondary, systems components weights (OEW)Secondary, support operations of advanced aerodynamics and control technologies to reduce drag and reduce noise
- **Technical Description:**
  – Ultra-High-Modulus, Ultra-High-Strength Fibers
  – Metal-Matrix Composites - titanium matrix composites to provide lower weight for very high strength applications such as landing gear
  – Very Tough Composites - Resin systems with greatly reduced susceptibility to impact damage and reduced curing temperatures to support lower cost
  – Thermoplastic Composites - thermoplastic resin systems support low cost manufacturing
  – High-Temperature Polymer Composites - Composite matrix systems capable of sustained operation at temperatures above 350F for use near engine and exhaust
  – Layer-by-Layer/Multifunctional nanocomposites for structures with integrated sensors and electronics to support structural health management and loads monitoring/active control
  – Ceramics/CMC Durable ceramic and ceramic matrix composites for elevated temperature load bearing structure

Structural Materials Success Criteria

Task Number	Task Name	Success Criteria	Alternate Steps if Unsuccessful
1	**Ultra High Modulus Ultra High Strength Fibers**	Very high aspect ratio wing designs not driven by sizing for aeroelasticity and gust/maneuver loads	Active control of aeroelastic response and loads alleviation
2	**Metal Matrix Composites**	Lightweight landing gear structures	Conventional materials, e.g., stainless steel
3	**Very Tough Composites**	Composite structure weight not driven by fracture toughness	Structural health management/prognosis to reduce fracture critical structural weight
4	**Thermoplastic Composites**	Sufficient strength for use in loaded secondary structures	Continued use of thermoset composites
5	**High Temperature Polymer Composites**	Use in engine nacelles	Titanium or high temperature aluminum depending on application
6	**Layer-by Layer-Multifunctional Nanocomposites**	Lightweight broad area sensing and distributed processing	Higher weight sensors and electronics
7	**Ceramics/Ceramic Matrix Composites**	Use in engines and nacelles	High temperature metals

Table 7.10 – Structural Materials Success Criteria

Structural Materials Roadmap

BCA – Advanced Concepts BR&T – Platform Performance Technology

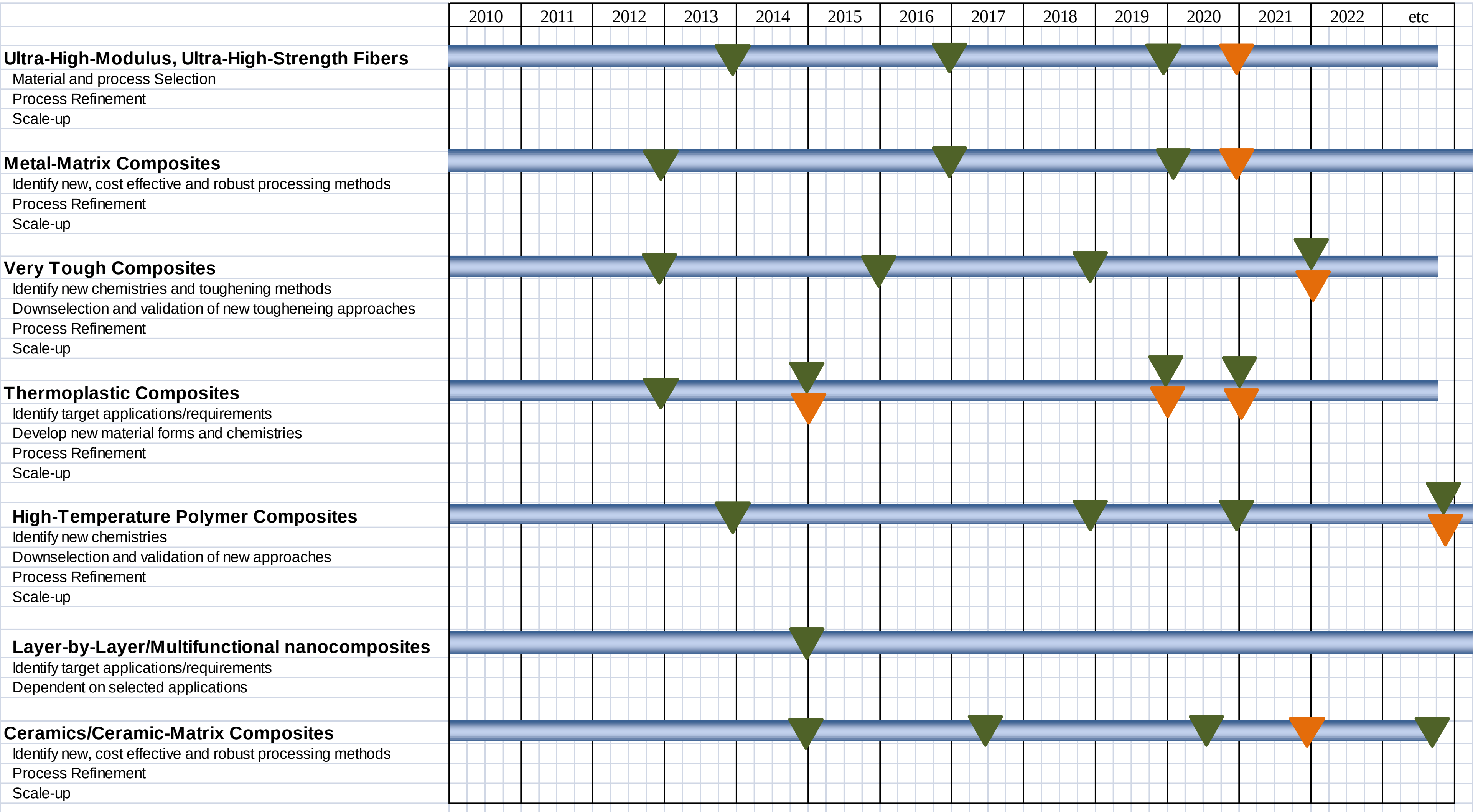


Figure 7.42 – Structural Materials Roadmap

Roadmaps for High Leverage Technologies

Structural Concepts

Structural Concepts Roadmap

- **Goals and Objectives:**
  - Implement advanced structural technologies currently under development enabling design, fabrication and operation of advanced high performance structural systems without the conservatism inherent in current structures.
  - Structural designs will include integrated systems functionality which will benefit both airplane systems operations as well lighter weight structures.
- **Performance Area and Impact:**
  - Primary, structural weight (OWE).
  - Secondary, systems components weights (OEW)
  - Secondary, support operations of advanced aerodynamics and control technologies to reduce drag and reduce noise
- **Technical Description:**
  - Reliability based design (RBD) and certification – quantify and actively manage structural design conservatism minimize excess weight while increasing airplane structural reliability
  - Structural Health Management (SHM) – know and manage the current state of the structures health throughout its life cycle
  - Advanced design concepts – design optimized structures using new design tools, advanced materials, fabrication and maintenance concepts
  - Multifunctional structures (MFS) – integrate system functionality into structures to reduce overall airplane weight and increase operational reliability through distributed redundancy
  - Adaptive structures – highly distributed actuation and sensing will enable airplanes to conformally change shape during flight to optimize L/D across a broad

Structural Concepts Success Criteria

Task Number	Task Name	Success Criteria	Alternate Steps if Unsuccessful
1	**RBD Analysis and Certification**	Use of probabilistic design methods for balanced design conservatism	Use of probabilistic design methods for secondary structure
2	**Structural Health Management**	Broad area monitoring of structure	Loads monitoring and structural hot spot detection (minimal weight improvement)
3	**Advanced Structural Design Concepts**	New structural concepts enable reduced weight	Conventional design
4	**Multifunctional Structures**	Structure with highly integrated systems functionality	Limited integration of wiring and thermal paths
5	**Adaptive Structures**	Reduced weight and complexity of conformal control surfaces and high lift systems	Reduce weight and complexity of rigid control and high lift surfaces

Table 7.11 – Structural Concepts Success Criteria

Structural Concepts Roadmap

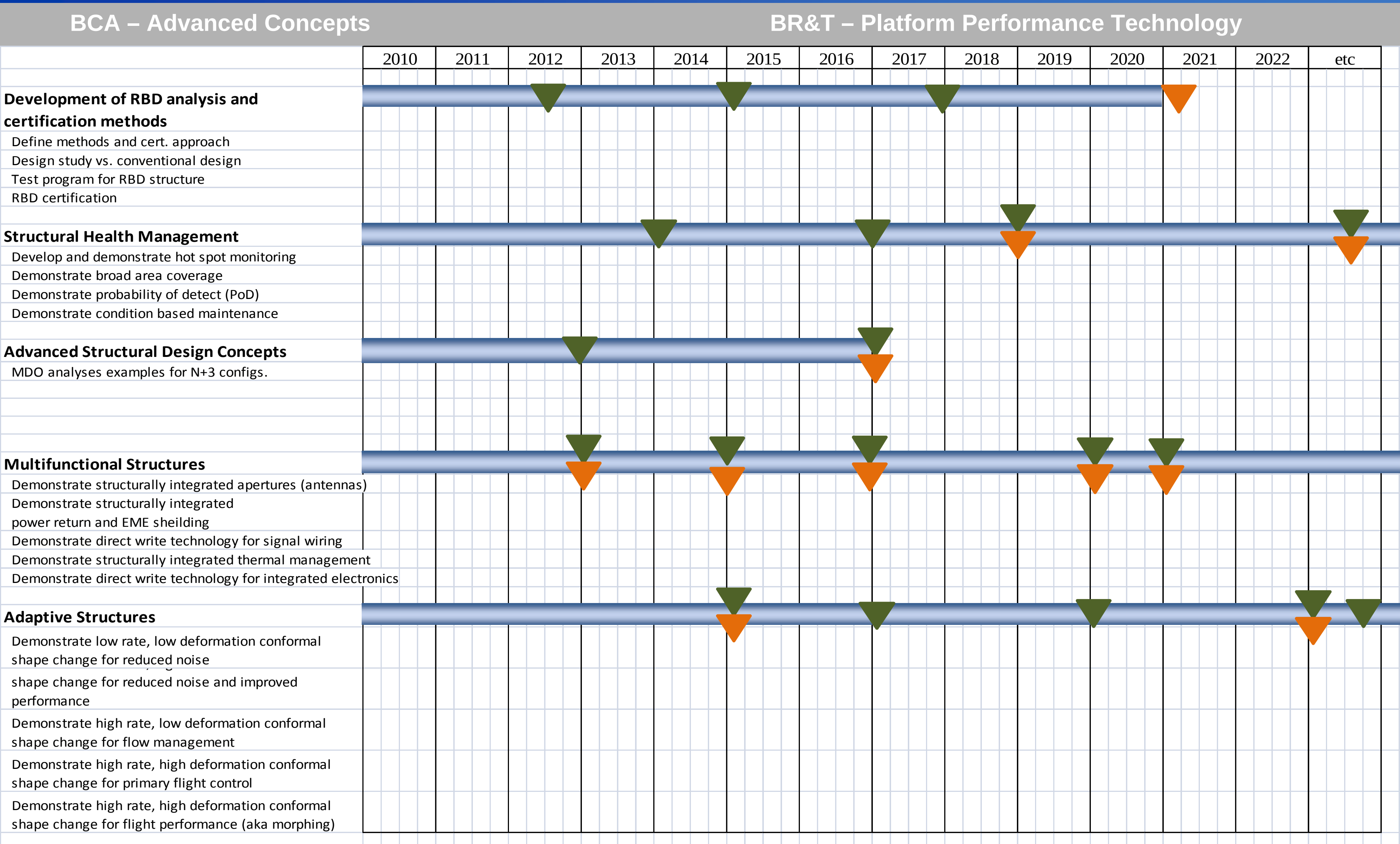


Figure 7.43 – Structural Concepts Roadmap

Roadmaps for High Leverage Technologies

High Span Strut Braced Wing

Integration Readiness

High Span Strut Braced Wing Tech Integration

- **Goals and Objectives:**
  - Develop and integrate technologies required to enable a high speed strut-braced wing.
- **Performance Area and Impact:**
  - Enable integration of high span strut braced wing allowing very high aspect ratio wings for low induced drag and natural laminar flow
- **Technical Description:**
  - Ultra-High-Modulus, Ultra-High-Strength Fibers
  - Low interference drag struts
  - Low interference drag nacelles for a highly integrated configuration
  - Active/Passive aeroelastic response for load control
  - Advanced high cruise CL supercritical wing design
  - Layer-by-Layer/Multifunctional nanocomposites
  - Natural laminar flow wing design

High Span Strut Braced Wing Technology Integration Success Criteria

Task Number	Task Name	Success Criteria	Alternate Steps if Unsuccessful
1	**Natural Laminar Flow**	NLF laminar design matches Active LFC	Achieve 50% of an Active LFC laminar Run
2	**Low Interference Drag Struts**	Integrate strut into wing-body for only strut parasite drag	Establish low interference levels
3	**Advanced Supercritical Wing Design**	Target 3% airplane drag improvement while attaining high design lift coefficient	Achieve 50% of target drag improvement
4	**Low Interference Drag Nacelles**	Integrate nacelle/pylon to wing body for only nacelle/pylon parasite drag	Establish low interference levels
5	**Active/Passive Aeroelastic Load Control**	Apan load traded for Aerodynamics and structural efficiencies to improve overall mission performance	Achieve improvement for one discipline
6	**Multifunctional Nanocomposites**	Lightweight broad area sensing and distributed processing	Higher weight sensors and electronics
7	**Ultra High Modulus and Strength Fibers**	Very high aspect ratio wing designs not driven by sizing for aeroelasticity and gust/maneuver loads	Active control of aeroelastic response and loads alleviation
8	**Vehicle Technology Integration**	Integrated vehicle design with advanced technology suite	Integrated vehicle design with all achieved technology advancements

Table 7.12 – High Span Strut Braced Wing Technology Integration Success Criteria

High Span Strut Braced Wing Technology Integration Roadmap

BCA – Advanced Concepts | BR&T – Platform Performance Technology

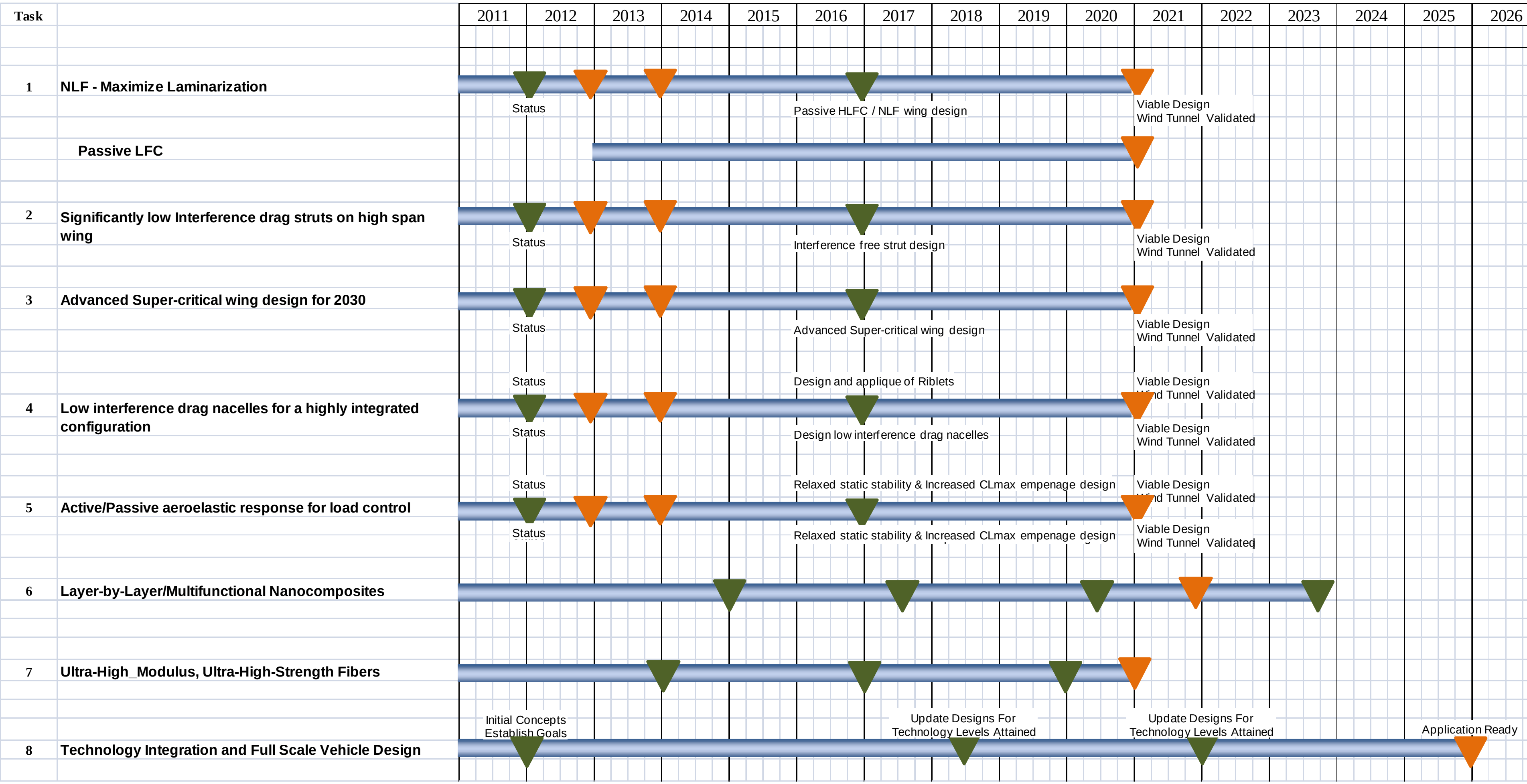
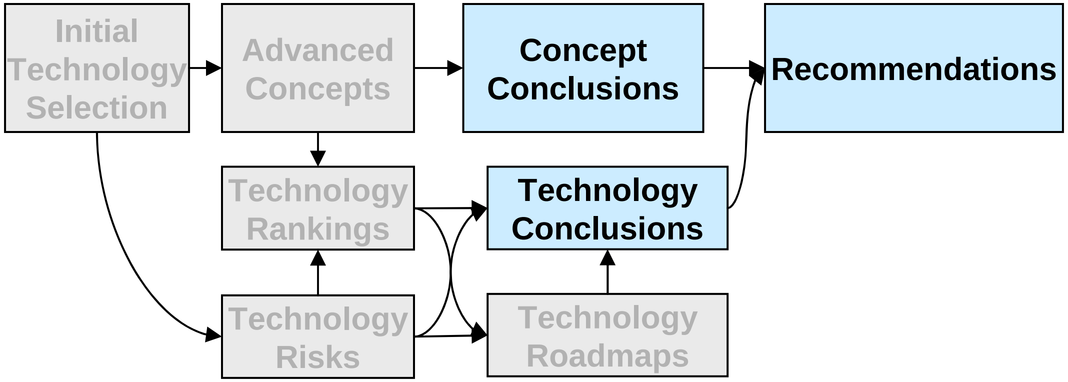


Figure 7.46 – High Span Strut Braced Wing Technology Integration Roadmap

12:15

- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- Concept Performance and Sizing from 12-Month Review
- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- **Summary, Conclusions, and Recommendations**
- Lunch
- Proprietary Session



Summary of Work Completed

- Development of a comprehensive future scenario for world-wide commercial aviation
- Selection of baseline and advanced configurations for study
- Generation of technology suites for each configuration
- Completion of point-of-departure analysis and sizing
- Detailed point design performance analysis and trade studies of baseline, reference, and advanced configurations
- Emissions, Noise, and TOFL calculations completed
- Parametric airport noise analysis completed
- Development of technology lists, risks, rankings, and roadmaps
- Developed recommendations for future work

Final Report

BCA – Advanced Concepts | BR&T – Platform Performance Technology

- Includes data in this and previous briefings
- Delivered March 31, 2010
- Has GE Proprietary appendix

Subsonic Ultra Green Aircraft Research
Phase I

Final Report

Contract Number: NNL08AA16B
Task Order: NNL08AD01T

March 31, 2010

Prepared by:
The Boeing Company

Marty Bradley, Principal Investigator
Christopher Droney, Deputy

Prepared for:
Erik Olson
NASA Langley Research Center

The Boeing Company
Boeing Research and Technology

NASA Contract NNL08AA16B – NNL08AD01T – Subsonic Ultra Green Aircraft Research – Phase I – Final Report

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Data Delivered to NASA

BCA – Advanced Concepts	BR&T – Platform Performance Technology

- **Mission description**
  - Range
  - Payload
  - Cruise Mach Number
  - TO & Land dist.
- **Configuration Geometry**
- **Drag Polars**
  - Low Speed
  - Cruise
- **Vehicle Component Weights**
- **Mission performance**
  - TOGW
  - Fuel Burn
    - Total
    - Per Mission Segment
  - Cruise Altitude
  - Noise Certification Numbers
  - Emissions
    - Landing-Takeoff (LTO)
    - Cruise

- **Propulsion System**
  - Overall Weight, key dimensions, emissions
  - Detailed Weight Breakdown
  - CAD geometry (if applicable)

    GE Proprietary version only
  - Projected Materials, Technologies Envisioned
- **Propulsion Performance Data**
  - Flight Conditions:
    - Sea-Level Static
    - Rolling Takeoff
    - Top-of-Climb
    - Cruise
  - Data Required
    - Net Thrust
    - Specific Fuel Consumption (SFC)
    - Ram Drag
    - Component Mass Flow
    - Component Total Pressure Ratio
    - Component Total Temperature Ratio
    - Component Appropriate Efficiency Parameter
    - Component Cooling Requirements

    GE Proprietary version only

- **All aircraft configuration data provided to NASA with unlimited data rights**
- **Propulsion data includes unlimited and restricted versions**

Conclusions – Fuel Burn

- **The NASA fuel burn goal of a 70% reduction is very aggressive**
- **A combination of air traffic management, airframe, and propulsion improvements were shown to achieve a 44-58% reduction in fuel burn for conventional propulsion**
- **The addition of hybrid electric propulsion to the technology suite has the potential for fuel burn reductions of 70-90%**
  - If electric energy is considered in a modified goal of “energy usage”, then a 56% or greater reduction in energy use is possible

Conclusions – Greenhouse Gases

- Although NASA did not establish a goal for greenhouse gas emissions, Boeing considered the goal of reducing life cycle CO_2 emissions
- The fuel burn reductions identified directly reduce CO_2 emissions as well
- Sustainable biofuels can reduce life cycle CO_2 emissions by 72% for conventional propulsion
- Even greater reductions possible with hybrid electric propulsion using “green” electrical power to charge the battery system

Conclusions – NOx Emissions

- **Landing and takeoff NOx emissions can be at or near the NASA goal of a 75% reduction from CAEP 6**
- **Benefits come from advanced combustor technology**
- **The use of electric power in the hybrid electric propulsion concept offers the opportunity for even lower emissions**

Conclusions - Noise

- **The original Phase I noise reduction goal to provide a 55 DNL contour at the airport boundary is difficult to achieve**
- **An investigation of airport characteristics shows that a 1.8 nm boundary distance is representative**
- **At this distance a 45 dB reduction relative to the SUGAR Free is needed to provide the 55 DNL contour**
- **However, the best performing configuration, SUGAR Ray, achieved only a 37 dB noise reduction and needs an impractically large 2.5 nm boundary to provide the 55 DNL contour**
- **To further reduce the airport boundary distance, or meet the updated NASA goal, requires significant additional reductions in aircraft noise**
- **Possible approaches:**
  - Greater use of electric power in the hybrid electric propulsion system
  - Noise optimized open fans or propellers
  - Additional trajectory noise optimization

Conclusions – Field Length

- Takeoff distances are designed to be approximately 8200 ft for the maximum range (3500 nm) takeoff weight
- For the average 900 nm range with reduced takeoff weight, distances of approximately 5000 ft are achieved
- The use of hybrid electric propulsion concept allows additional application of power for takeoff, possibly lowering the takeoff distance even more
- This was achieved without adding aggressive high lift technologies
- For the study, we assume that a takeoff distance of approximately 5000 ft for the average range mission is sufficient for operation at an adequate number of airports to support necessary operations
- We chose not to expend limited study resources to further investigate configurations and technologies needed to achieve shorter takeoff distances

Conclusions – Advanced Configurations

- **The SUGAR High configuration has potential to beat the conventional configuration (Refined SUGAR) with regard to fuel burn**
  – However, the present uncertainty in the wing weight prevents any definitive conclusion at this time
- **The SUGAR Ray HWB configuration is clearly the quietest due to shielding**

Results Compared to N+3 & Additional Boeing Goals

BCA – Advanced Concepts   BR&T – Platform Performance Technology

Goals	Refined SUGAR		SUGAR High		SUGAR Volt		SUGAR Ray	
	Base	Opport.	Base	Opport.	Base	Opport.	Base	Opport.
Fuel Burn -70%	**-44%**	**-54%**	**-39%**	**-58%**	**-63%**	**-90%**	**-43%**	
GHG -70%	**-72%**	**-77%**	**-69%**	**-79%**	**-81%**	**-95%**	**-75%**	
Energy -70%	**-44%**	**-54%**	**-39%**	**-58%**	**-56%**		**-43%**	
LTO NOx Emissions -75% CAEP 6	**-58%**		**-72%**		**-79%**	**-89%**	**-72%**	
Noise 55 DNL (1.8 nm)	**6 nm**		**4.7 nm**		**<4.7 nm**		**2.5 nm**	
Noise -71 dB								
Field Length (ave. mission)	**5500 ft**	**4900 ft**	**6000 ft**	**5300 ft**	**4400-6000 ft**	**4000 ft**		

Far from goal

Does not meet goal

Nearly meets or meets goal

Exceeds goal

Conclusions - Technologies

- **A wide portfolio of technologies is needed to achieve the NASA N+3 goals**
- **Significant improvements in air traffic management, and aerodynamic, structural, system, and propulsion technologies are needed to address fuel burn goals**
- **Biofuels are needed to further reduce greenhouse gas emissions**
- **Advanced combustor technology is necessary to meet NOx goals**
- **Even more aggressive engine and airframe noise reduction technologies than we assumed in this study are needed**
- **The hybrid electric engine technology is a clear winner, as it has the potential to improve performance relative to all of the NASA goals**

Technology Ranking Summary

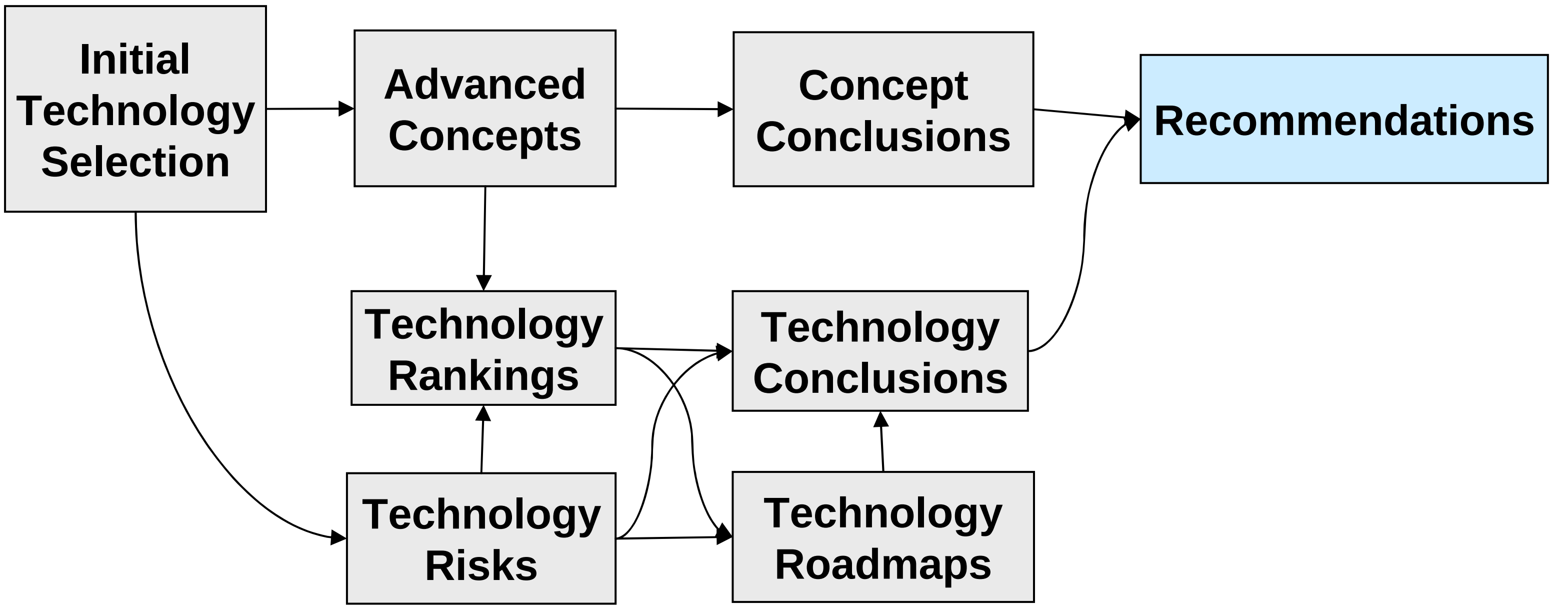
Ranking	Technology or Technology Group	Goals
Game-Changing	Hybrid Electric Propulsion & High Performance Modular Batteries	Noise, Emissions, Fuel Burn, TOFL
Critical	Advanced Combustors	Emissions
Critical	Biofuels	Emissions
Critical	NextGen ATM	Emissions, Fuel Burn
Critical	Engine Noise Treatments	Noise
Critical	Aero Technologies (Inc. Laminar Flow)	Noise, Emissions, Fuel Burn, TOFL
Important	Engine Technologies	Fuel Burn
Important	Airframe Acoustic Technologies	Noise
Important	Airframe Materials & Structures	Fuel Burn
Important	Advanced Subsystems	Emissions, Fuel Burn

A wide portfolio of technologies is needed to achieve the NASA N+3 goals

SUGAR Phase 1 Process

BCA – Advanced Concepts

BR&T – Platform Performance Technology



Recommendations based on technology and concept analysis evaluated against NASA N+3 goals

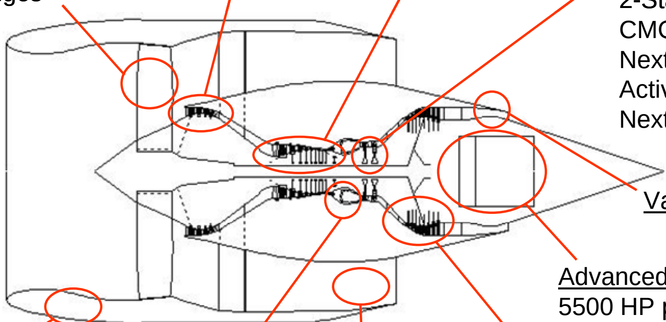
Recommendations Based On Phase 1 Results

1. Additional design and analysis of hybrid electric gas turbine propulsion
2. A comprehensive study of high aspect ratio truss braced wings
3. Additional noise technologies
4. A follow-on to this study to consider the synergistic benefits of methane and/or hydrogen fuel
5. A follow-on to this study to include the large aircraft size class
6. An aircraft power system study
7. A follow-on to this study to include the regional size class

Additionally, work should continue to investigate and validate the performance for the HWB configuration

Recommendation - Hybrid Electric Propulsion

1. **Additional design and analysis of hybrid electric gas turbine propulsion architectures**
   - Integration on one or more other configurations (like the Refined SUGAR and/or SUGAR Ray)
   - A noise analysis for the hybrid electric propulsion system needs to be conducted to determine potential noise benefits for operating on partial electric power



Advanced Composite Fan
1.35 PR, 89.4" fan
Advanced 3-D aero design
Sculpted features, low noise
Thin, durable edges

4-Stage Booster

Ultra-high PR core compressor
59 OPR, 9 stages
Active clearance control

HPT
2-Stage
CMC nozzles + blades
Next-gen ceramic
Active purge control
Next-gen disk material

Variable core nozzle

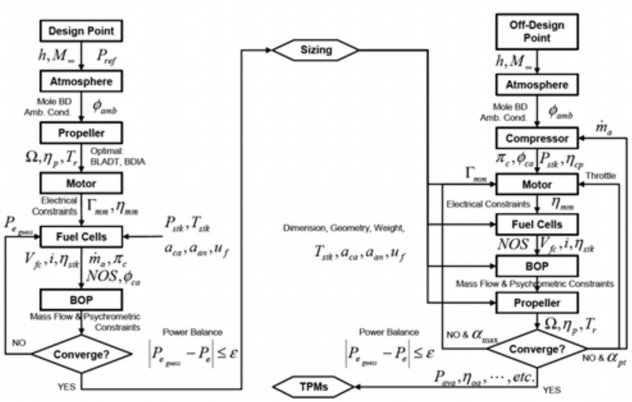
Advanced Motor & Gearbox
5500 HP power output
Advanced gear box

LPT
8-Stage
Highly Loaded Stages
CMC blades/vanes (weight)

Advanced nacelle
Slender OD
Unitized composite
Advanced acoustic features

Advanced combustor

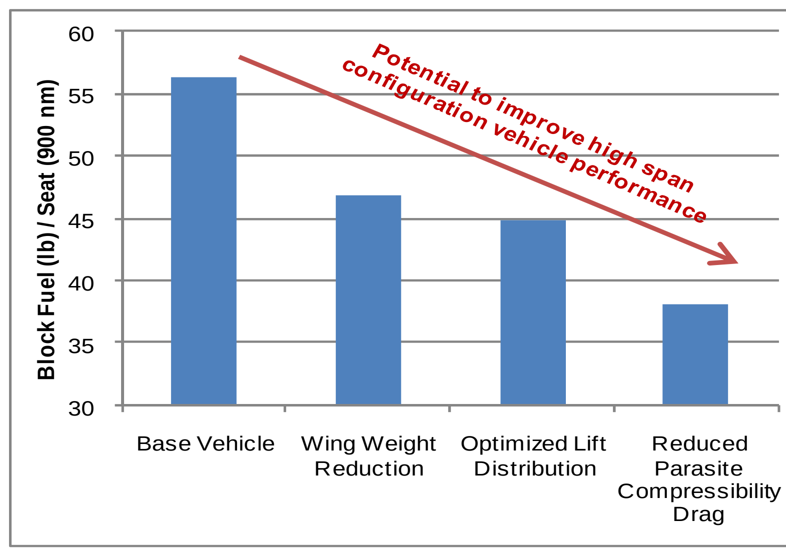
Integrated thrust reverser/VFN
Highly variable fan nozzle



Recommendation – Truss-Braced Wing

2. A comprehensive study of high aspect ratio strut/truss braced wings, accounting for coupled aerodynamics, structures, materials, propulsion, control, and airport compatibility.

- Making this wing aerodynamically effective while controlling weight is key to enabling this high L/D configuration.
- A detailed finite element model is needed, and an aeroelastic test is necessary to validate the structural analysis and to determine the weight of the wing.
- The high aspect ratio wing aerodynamics at the Mach 0.7 cruise condition and off design requires additional optimization and experimental validation.



Recommendation - Noise Technology

3. **Additional noise technologies need to be identified and validated to achieve the updated NASA -71 db noise goal.**
   - This could include use of trajectory optimization, greater use of electric propulsion, turboprops, and low noise propellers
   - Airframe and tail shielding should continue to be investigated in HWB and conventional configurations

Configuration	SUGAR Free	SUGAR Ray
Propulsion	CFM-56	gFan+
Relative Noise	0 db*	-37 db*

Phase 1 results not sufficient to meet updated NASA noise goal

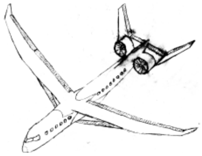
CORNERS OF THE TRADE SPACE	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	-71 dB
LTO NOx Emissions (below CAEP 6)	better than -75%
Performance: Aircraft Fuel Burn	better than -70%
Performance Field Length	Exploit metroplex* concepts

*** Technology Readiness Level for key technologies = 4-6

* Concepts that enable optimal use of runways at multiple airports within the metropolitan area

Airframe Acoustic Technologies:
- Low speed high lift devices to reduce thrust required for cutback flyover and approach conditions
- Inlet noise shielding from top of wing mounted engines
- Rear jet and exhaust fan duct noise shielding from rear deck/platform for flyover and approach noise reduction and twin verticals for lateral noise reduction and exhaust nozzle designs for distributed jet noise source reduction from shielding
- Airframe noise reduction methods including wing plan-form (airfoil design), main gear fairings, lift & control surface treatments (sealing etc)
- Rear fan duct noise treatment methods

Advanced Engine Acoustic Technologies:
- See Engine Acoustic Roadmap



* Relative to SUGAR Free CFM-56, not "cum below Stage 4". These numbers are not directly comparable. Absolute SUGAR Free CFM-56 value is proprietary.

Recommendation - H2 Fuel Technology

4. **A follow-on to this study to consider the synergistic benefits of methane and/or hydrogen fuel**
   - Fuel high heating value
   - Thermal management advantages
   - Fuel cells w/o reformers
   - Superconducting electric propulsion
   - Highly integrated power systems

“SUGAR Freeze”?

Recommendation - Large Aircraft

5. A follow-on to this study to include the large aircraft size class

– It is anticipated that some technologies will become more important as the length of the cruise segment is increased

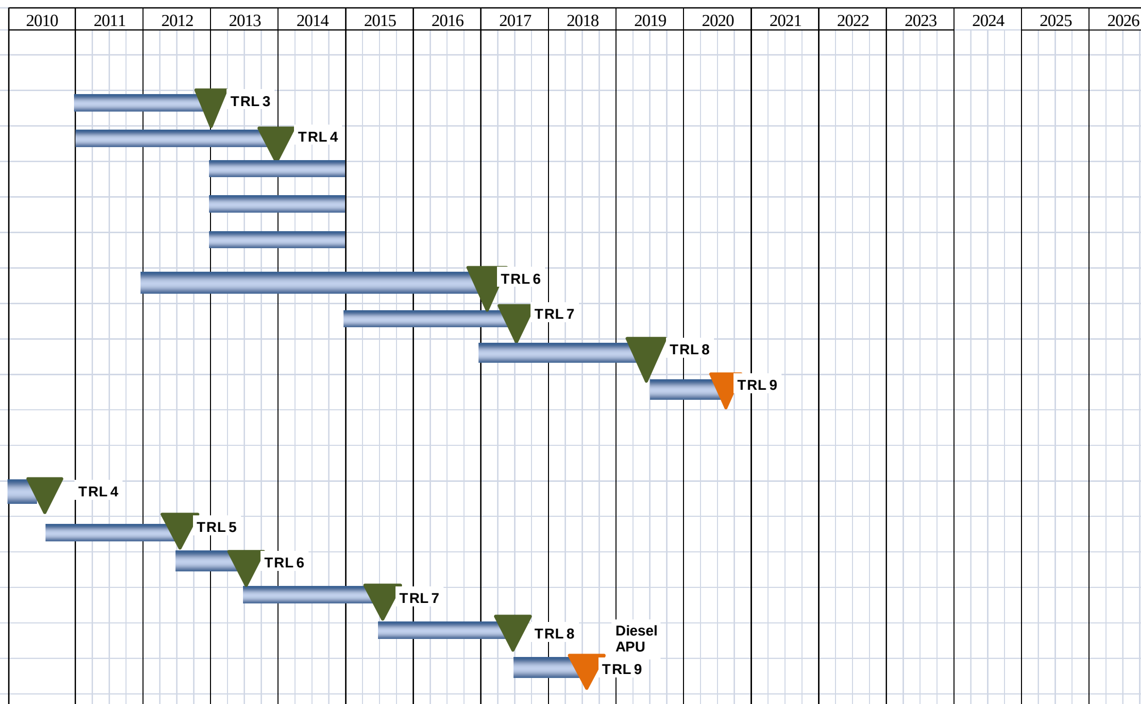
"SUGAR Beet"?

2030 Fleet			
	Regional	Medium	Large
Number of Aircraft	2,675	22,150	7,225
Family Midpoint # of Seats	**70**	**154**	**300**
Avg. Distance	**575**	**900**	**3,300**
Max Distance	**2,000**	**3,500**	**8,500**
Avg. Trips/day	6.00	5.00	2.00
Avg. MPH	475	500	525
Fleet Daily Air Miles (K)	8,500	100,000	55,000
Daily Miles	3,200	4,500	7,600
Daily Hours	6.92	9.23	13.96

Recommendation - Power Systems

6. **An aircraft power system study to determine the best architecture for aircraft power, including diesel and conventional APUs, fuel-cells, batteries, and both engine power take-off and bleed air**
   – This study should include traditional, more-electric and all-electric aircraft system architectures, per aircraft size class

TRL	Task	
	1	Adaptive Power Management
3	1.1	Intelligent Energy Management Architecture
4	1.2	Adaptive Load Management Models and Simulators
5	1.3	Intelligent components
5	1.4	Self-powered passenger control units
5	1.5	Self-powered wireless sensors
6	1.6	High Power Energy Harvesting
7	1.7	Prototype Testing and Demonstration
8	1.8	Qualification and Certification tests
9	1.9	Flight Ready
	2	Diesel APU
4	2.1	Breadboard demo in sub-atmospheric test chamber
5	2.2	Ground test of prototype scaled unit
6	2.3	Prototype test on the ETD at altitude
7	2.4	Beta unit demonstration
8	2.5	Qualified through certification tests
9	2.6	Flight proven



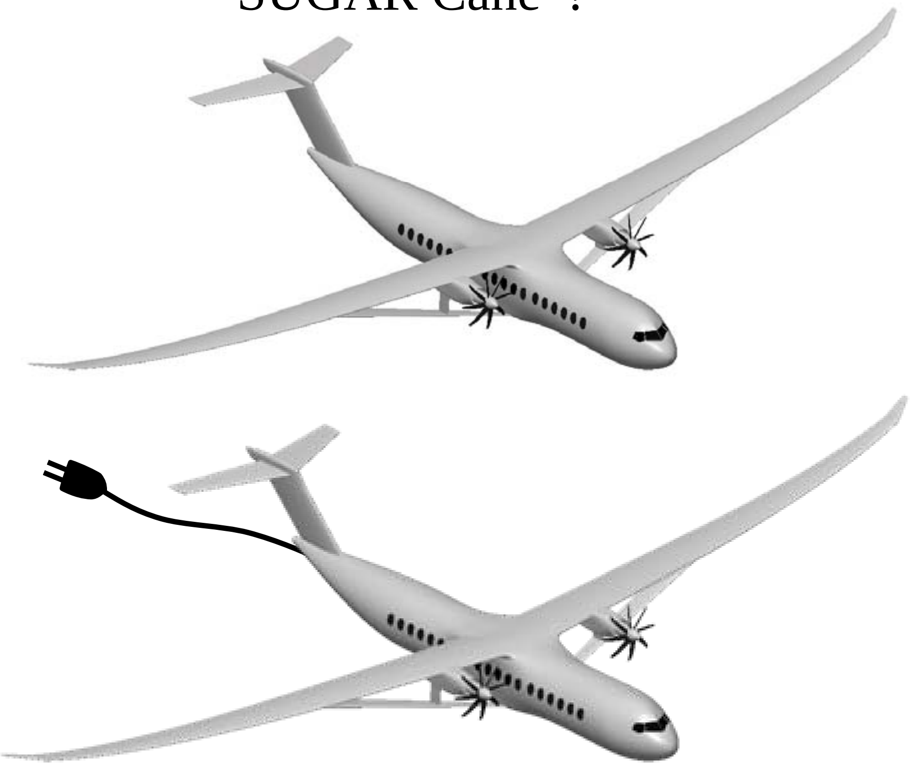
Recommendation - Regional Aircraft

7. A follow-on to this study to include the regional size class

– Special emphasis should be placed on field length & electric/hybrid electric propulsion

2030 Fleet			
	Regional	Medium	Large
Number of Aircraft	2,675	22,150	7,225
Family Midpoint # of Seats	**70**	**154**	**300**
Avg. Distance	**575**	**900**	**3,300**
Max Distance	**2,000**	**3,500**	**8,500**
Avg. Trips/day	6.00	5.00	2.00
Avg. MPH	475	500	525
Fleet Daily Air Miles (K)	8,500	100,000	55,000
Daily Miles	3,200	4,500	7,600
Daily Hours	6.92	9.23	13.96

“SUGAR Cane”?



Battery Electric Propulsion May Have Potential Application for Regional Aircraft

- **N+3 Electric Trade Configuration (SUGAR Volt)**
  - Battery Propulsion
  - 3500 NM Max range requirement ignored

"-100%" fuel burn
Also need to look at energy usage

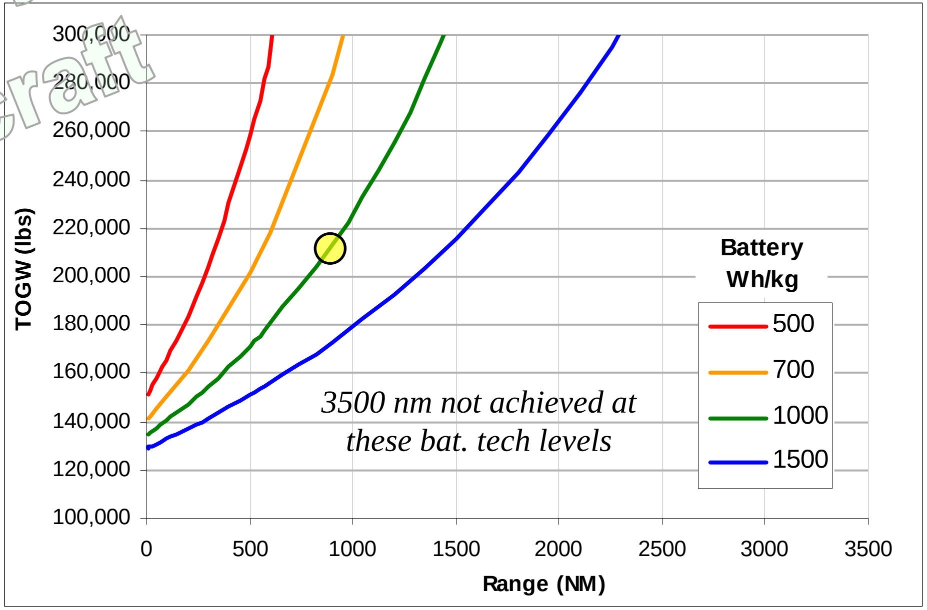
Conditions and Assumptions

Mach	0.65
Max Range (nm)	900
Range for Fuel Burn	900
TOFL (sea level):	7,000
ICA	42,207
Strut?	y
Climb at ICA (fpm)	300
Carbon Wt redctn factor	0.9
Cl takeoff	2.4
2nd segment climb (Cl)	1.4
Reserves, N + ("0","3")	3.0
SFC Hit at Divert	50%
SFC Improv over CFM56	25%
Laminar Credit	y
Riblet Credit	y
Trip Fuel Reduction (Routing)	5%
Tail Relaxed Size Factor	0.9

Vehicle Specifications

AR	24.0
Sref (ft^2)	2,405
Effective Span (ft)	240
Root t/c	0.130
Tip t/c	0.085
Ct/Cr	0.18
Cruise Cl	0.833
A (sweep)	20.00
L/D	32.17
ICA	42,207

TOGW	211,616
Fuel Burn (900nm)	0
Battery Weight:	53,545



≥1000 W-h/kg batteries required to achieve 900 nm range with reasonable TOGW

Also, look at hybrid gas turbine battery electric propulsion for possible earlier application for regional aircraft

Recommendation - HWB

- **Additionally, work should continue to investigate and validate the performance for the HWB configuration**
  - It is anticipated that the HWB configuration will be emphasized in the N+2 Environmentally Responsible Aviation (ERA) program
  - Air Force, NASA, Boeing, (and other) projects are advancing the HWB configuration and related technologies
  - The HWB concept should continue to be carried in the N+3 program, as most N+3/N+4 technologies can be applied to the HWB concept as well

Thanks …

BCA – Advanced Concepts

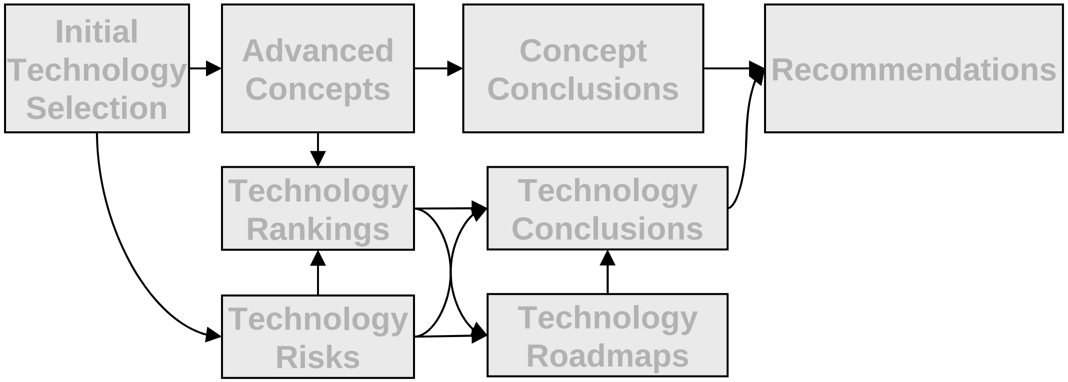
BR&T – Platform Performance Technology

SUGAR Phase 1 Final Review

BCA – Advanced Concepts | BR&T – Platform Performance Technology

1:00

- Task Flow & Schedule
- Future Scenario, Concepts, & Technologies from the 6-Month Review
- Concept Performance and Sizing from 12-Month Review
- Technology Activities
  - Risk Assessment / Rankings / Roadmaps
- Summary, Conclusions, and Recommendations
- **Lunch**
- Proprietary Session



SUGAR Phase 1 Final Review

BCA – Advanced Concepts BR&T – Platform Performance Technology

2:00

- Task Flow & Schedule
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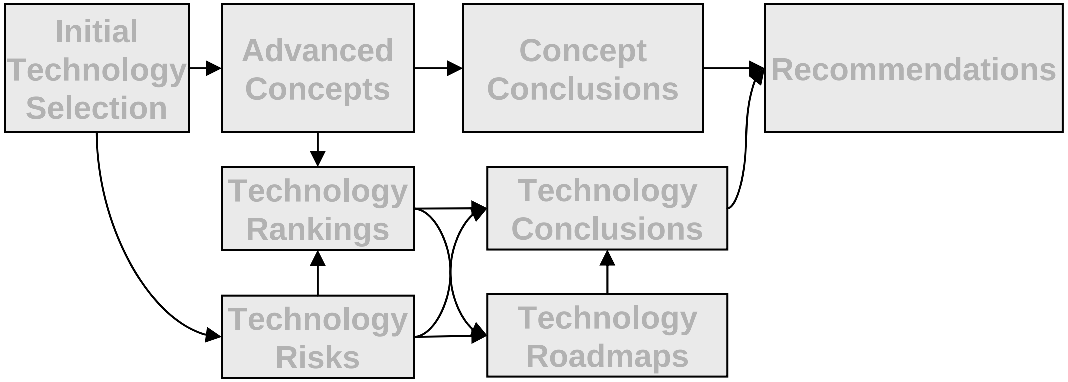


Back Up Material

CMO Methodology

- Forecast matches traffic derived primarily from GDP growth with network and fleet plans built up for individual airlines over 20 years
- 149 individual airlines and regional groups – cargo, charter, regional, LCC and mainline subsidiary carriers are also included
- 64 traffic flows with both intra (within) and extra (between)
- Representative new markets (city pairs) generated by airline
- Airplane retirements are based on individual airline fleets – secondary passenger use and/or cargo conversions included

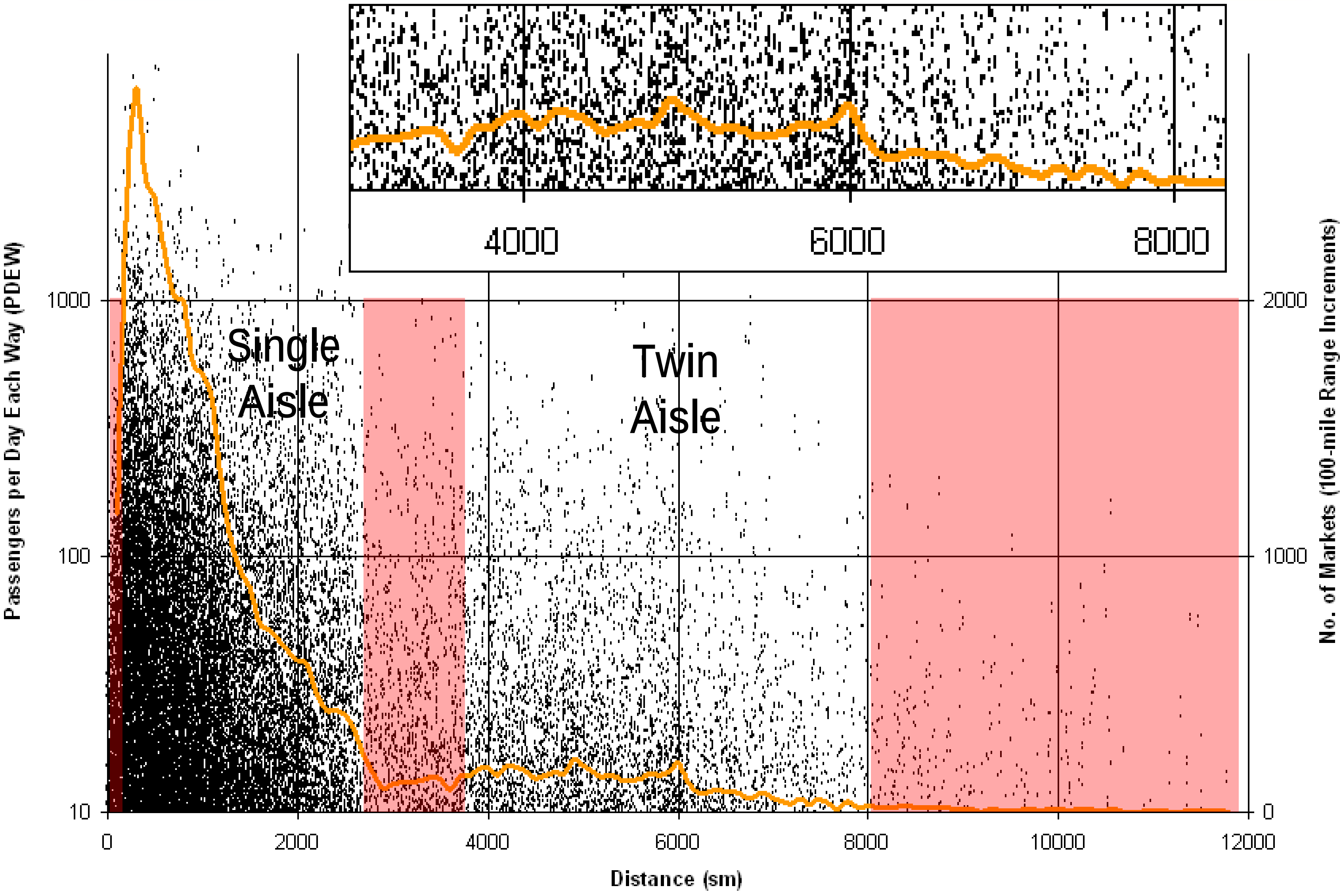
Definition of 'N'

- Grouped by fuel burn, aero/structure technology, and noise

Generation		EIS
1st (N-3)	707, DC-8, 727, 737-200, DC-9	1955-1970
2nd (N-2)	747, DC-10, L1011, A300	1970-1980
3rd (N-1)	737-300, MD-80, A320, 757, 767, A310, 747-400, CRJ, ERJ	1980-1995
4th (N)	777, 737NG, A330/340, A380, E190/195	1995-2005
5th (N+1/2)	787, A350, CSeries, MJet…	2005-2015
6th (N+1 & N+2)	2015-2020	2015-2020
7th (N+3)	2030-	2030-

256

World Origin & Destination
Geography and Economics Limit Demand



Action Items from 6-Month Review

1. **Future Scenario – Elaborate on how increased congestion impacts the projected growth in aircraft and flights – *see slide***
2. **Reserve assumptions – *Used standard Boeing method applicable to both U.S. and International flights***
3. **Consider an alternative version of "Refined SUGAR", a "Super Refined SUGAR" which would allow a direct comparison to "SUGAR High" and other advanced configurations – *see slide***
4. **At the 12-month review, discuss the data package deliverable – *later in this presentation***
5. **Look at using "Carson's Speed" for selecting cruise Mach – *see slides***
6. **Note that Dennis Bushnell says the optimum altitude is 27,000 ft to avoid contrails – *we have not limited cruise alt, but looked at sensitivity***
7. **Virginia Tech & Georgia Tech are doing a strut-braced wing study. NASA will invite us to the next workshop when data is being shared. – *see slide***

General Comment: Make sure to document all of the technology and operations downselect decisions – *Tech tables, workshop documentation, final report*

Action Item #1 – Future Scenario Congestion Modeling

- **The CMO utilizes a top down economic/traffic forecast, and a bottom up airline route network forecast. While neither of these processes utilize an explicit "Congestion model“, they each have assumptions of congestion built into them.**
  - The economics and traffic is derived from history and forecasts. The real system if dynamic and new airplanes, airports and services are created to capture the value of time that congestion is wasting.
    - *Example JFK 1985-2009 (see notes page)*
  - The other side of the CMO forecast takes a more direct approach to congestion issues. During the forecast process, the regional forecasters deploy airplanes, routes, and frequencies they keep in mind current and proposed investments and then limit the growth at the most constrained airports/regions. This results in faster growth beyond the current core airports.
- **This process leads to a slower than anticipated growth in the average size of airplanes, with frequency and more capable airplanes allowing growth in the system.**

Action Item #2

- **Are there different reserves for domestic and international flights? A NASA person thought so and that we were using the international type reserves.**
- ***Answer from Jim Conlin, BCA Performance:***
  – *Most likely the comment refers to the difference between FAR International and FAR Domestic rules, which are slightly different from each other. **The rules we are using are based on Boeing Typical Rules which are not the same as either of those.** Boeing uses what we refer to as Typical Mission Rules for all our general and brochure Performance data and comparisons, so that all of the airplane data generated are comparable. Were we to use a different rule set for "International", "Domestic", and even "Regional" airplanes, we would have to carry around different sets of data and comparisons, because data generated with different rule sets would not be directly comparable. So, while we could use different rule sets for the different configurations, it is easier to just use one representative mission rule set and eliminate that one variable and another source of confusion.*

Action Item #3

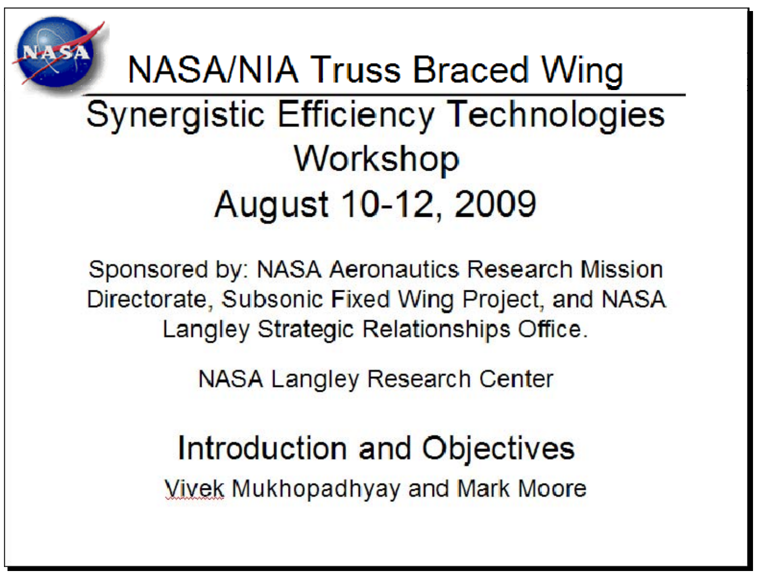
- ***Boeing Recommendation: Do not add a 6th point design configuration (Super Refined SUGAR) to the detailed configuration and sizing analysis***
- ***Instead show "Super Refined SUGAR" as a trade/sensitivity study to allow NASA to see the impact of technologies and the span constraint applied selectively to the "Refined SUGAR"***
  - *Advanced engine as "SUGAR High" & "SUGAR Ray"*
  - *Aerodynamic technologies as "SUGAR High" and "SUGAR Volt"*
  - *Advanced structural/material technologies*
  - *Span constraint relaxed – Include sensitivity study looking at wing span constraint, wing folding, and strut bracing*

Action Item #7

- **We participated in the Truss Braced Wing workshop**

Trip Report:

Truss-Braced Wing Synergistic Efficiency Technologies Workshop



NASA/NIA Truss Braced Wing Synergistic Efficiency Technologies Workshop
August 10-12, 2009

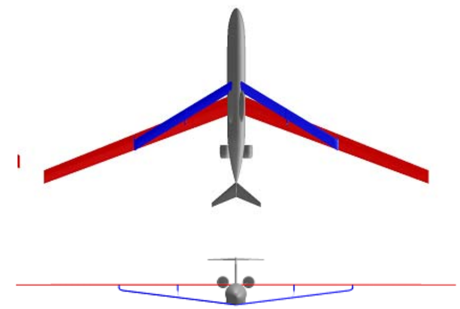
Sponsored by: NASA Aeronautics Research Mission Directorate, Subsonic Fixed Wing Project, and NASA Langley Strategic Relationships Office.

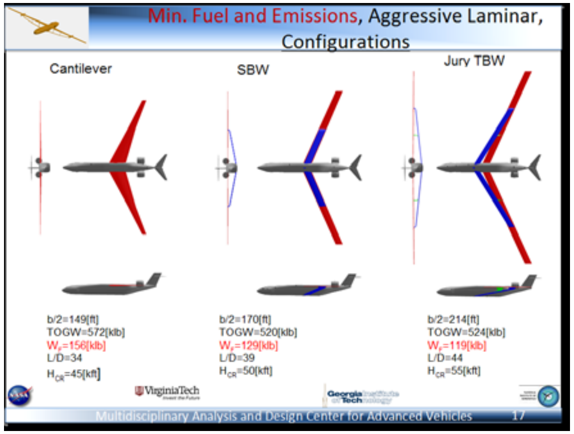
NASA Langley Research Center

Introduction and Objectives
Vivek Mukhopadhyay and Mark Moore

- There were approximately 70 attendees
- Host: Mark Moore of NASA Langley
- Location: NIA National Institute of Aerospace, Hampton VA

Zach Hoisington
Boeing Research & Technology



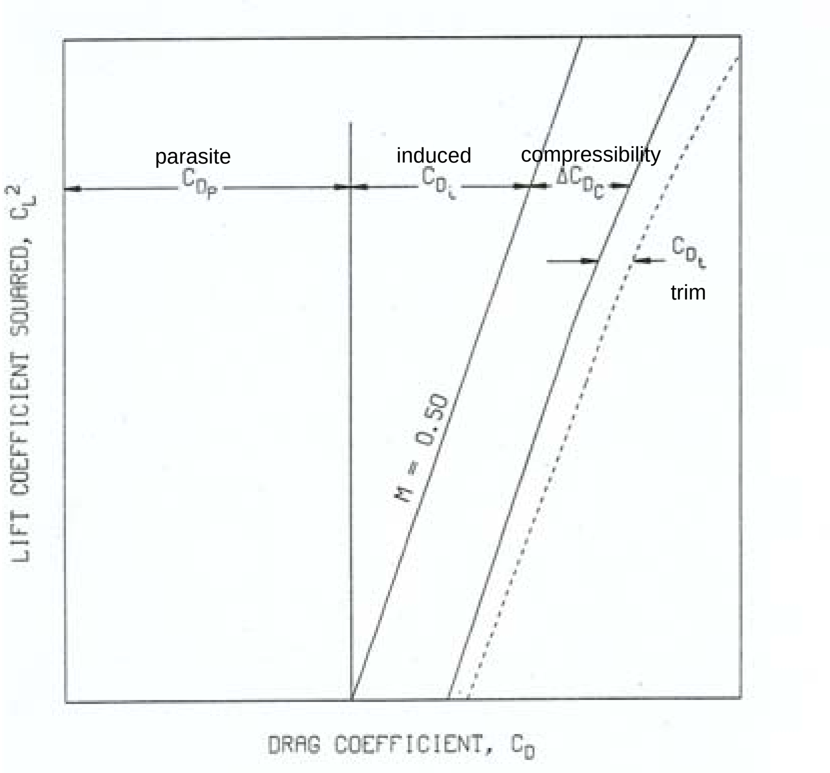


Aerodynamics Cruise Drag Method

- **CASES is used to develop a high speed buildup**

CASES Standard Build-Up : $C_D = C_{Dp} + C_{Di} + C_{Dc} + C_{Dtrim} + \Delta C_{D\ power}{}^{*}$

CASES drag methods are based on empirical data. Increments for technology such as laminar flow and riblets are applied to C_{Dp} and C_D after the buildup is completed



* For Propeller/Open Fan Datasets Only, Based on Momentum Theory, Not part of CASES Buildup

Low Speed Aerodynamics

CASES is also used for the low speed buildup and relies on empirical methods. Powered and Technology increments are applied after CASES dataset is complete

Conceptual Low Speed plus powered increment

Lift

$$C_L = C_L\,(C_{L_{taxi}},\ C_{L_{Vmu}},\ C_{L_{max}}) + \Delta C_{L\ power}{}^{*}$$

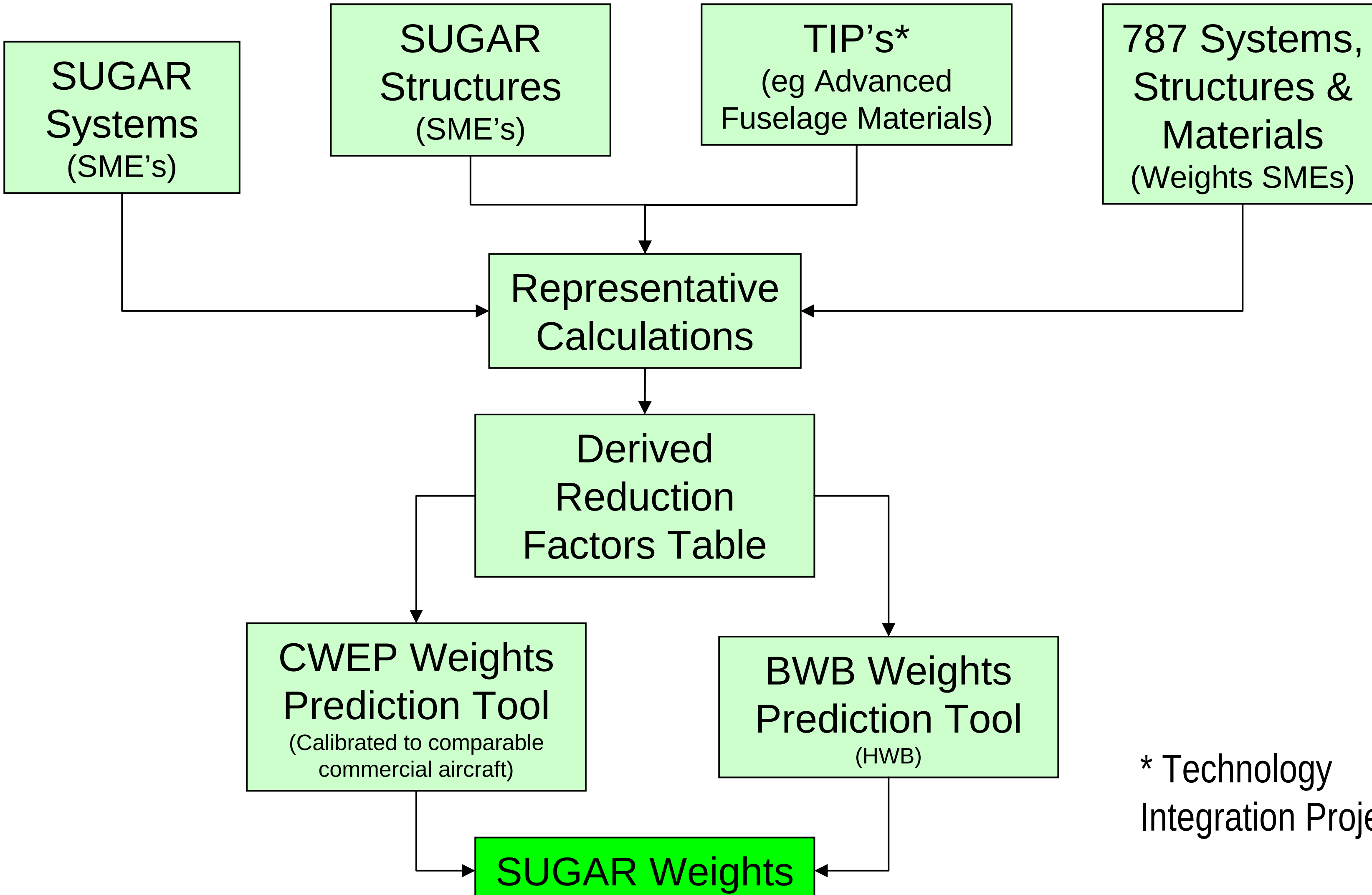
Drag

$$C_D = C_{D_{o\ Clean}} + C_{D_{Twist}} + C_{D_{Profile}} + C_{D_{Induced}} + C_{D_{Flap}} + C_{D_{Trim}} + \Delta C_{D\ power}{}^{*}$$

C_{Do} Clean is taken from C_{Dp} of the high speed buildup

* For Propeller/Open Fan Datasets Only, Based on Momentum Theory, Not part of CASES Buildup

SUGAR Mass Properties Methods



* Technology Integration Projects

SUGAR Mass Properties Reduction Factors

- Wing Bending Material Reduction = 26%
  - Based on load alleviation and advanced composites & joining methods
- Tail Reduction = 15%
  - Based on advanced composites
- Fuselage Reduction = 12%
  - Based on advanced composites (11%), and joining methods (1%)
  - Weights (lb) Based on Historical Fuselage Details
  - 14,283 lb material uses Advanced Composites out of 17,472 lb total Fuselage

	Actual Weight	% Reduction	Wt Reduction
Total Weight of Fuselage	**17,472**	**11%**	**1875**

Fuselage Reduction Items	**14,283**		**1875**
Doors (see sample below)	2,503	10%	250
Cockpit Structure	248	15%	37
Keel	195	15%	29
Pressure Panels	305	15%	46
Floor Support	1,161	15%	174
Fuselage Longerons & Intercostals	2,407	15%	361
VSCF Doghouse	74	15%	11
Skin	4,552	15%	683
Bulkheads & Frames	2,838	10%	284

Sample Passenger Entry Door	**291**	**10%**	**28**
Jamb	102	10%	10
Door Structure	82	15%	12
Frame I - Fuselage Nose	38	15%	6

SUGAR Mass Properties Reduction Factors

- Landing Gear Reduction = 0.6% (of TOGW)
  - Based on metal matrix composites
- Nacelle Structure Reduction = 2%
  - Based on ceramics in core cowl
- Onboard Structural Health Management Addition = +100 lb
- Insulation Reduction = 5%
  - Based on premium fiberglass and polyimide foam
- Lightweight Seats Reduction = 20%
- Paint Reduction = 44 lbs
  - Based on lighter paint and application methods
- Advanced Heat Exchanger Reduction = 50%
  - Based on microtube designs and composite / polymer materials
- Signal Wiring Reduction = 50%
  - Based on optical fiber

Performance Methods

- **Mission Analysis**
  - Boeing Mission Analysis Program (BMAP)
  - Fully Models Mission Profile

- **Takeoff Analysis**
  - Low Speed Performance System (LSPS)

- **Airplane Sizing**
  - Airplane Design Navigator (ADNav)
  - Utilizes BMAP for Mission Analysis and LSPS for Takeoff Analysis
  - Explore Design Space Varying Wing Area and Engine Scale
  - Capability to Plot Contours of All Parameters and Constraints
  - Explore Sensitivities to Constraints

Performance Methods

Required Inputs

Airplane Weight Data
- Basic OEW
- Sizing Data
  - f (Sw, TOGW, Fn)

Airplane Drag Data
- Basic Polar
- CDPmin Buildup
- Takeoff Polars
- Stall Lift Coefficients

Airplane Propulsion Data
- Takeoff Thrust / Fuel Flow
- Cruise Thrust / Fuel Flow
- Idle thrust / Fuel Flow

Basic Airplane Performance
- Mission Performance
- Takeoff Field Length

Size Airplane (Wing and Engine) to Meet Performance Requirements
- Design Range
- Climb Performance
- Takeoff Field Length

Emissions Methods

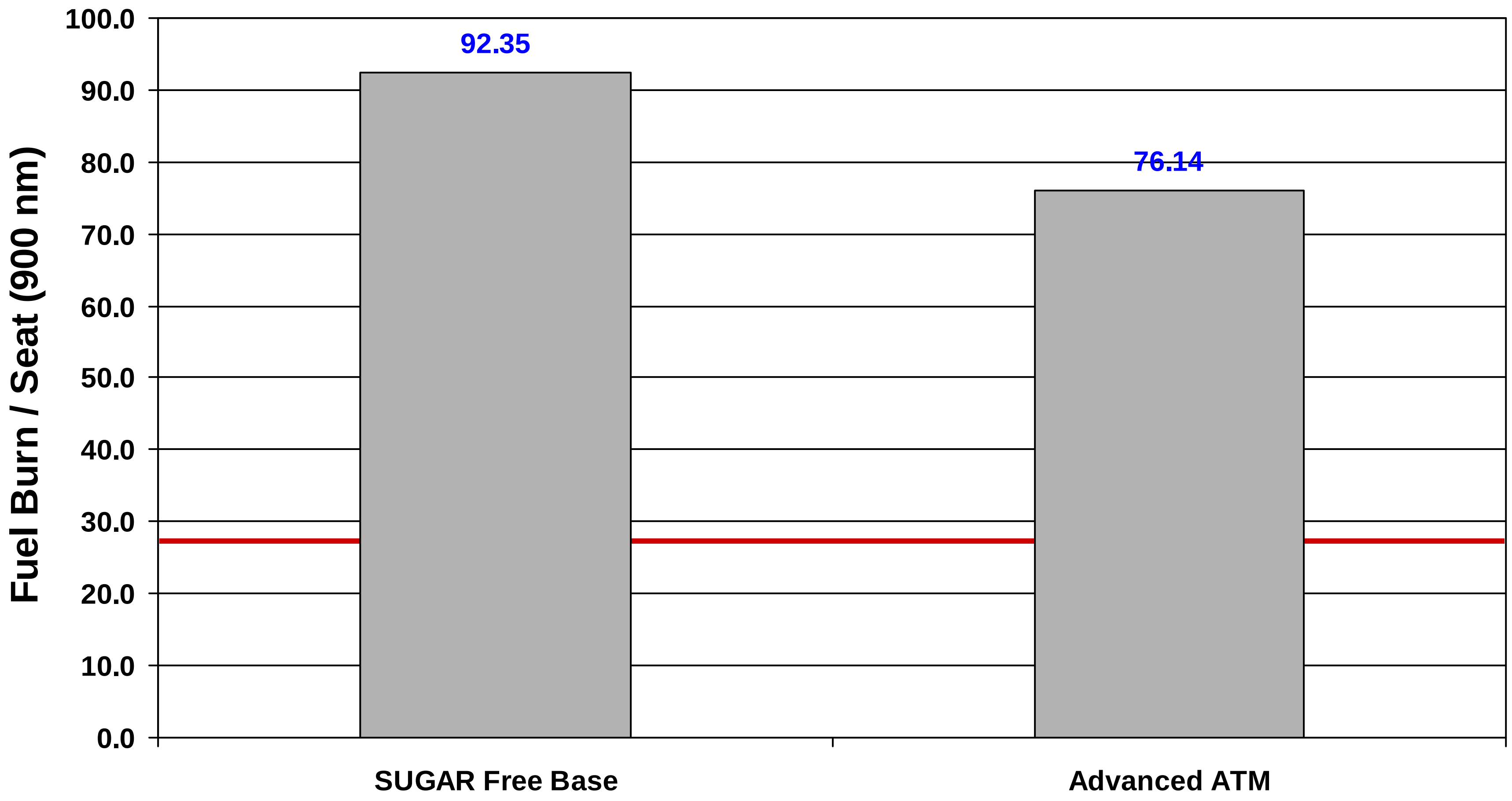
Landing and Takeoff Emissions:

- **GE supplies CAEP 6 reference emissions level for each engine**
  - CAEP 6 numbers are non-dimensionalized by thrust

Other Emissions:

- **CO_2 emitted by aircraft**
  - Conventional fuels
  - Biofuels with 50% lifecycle reduction in CO_2

SUGAR Free Performance Trades Summary



Refined SUGAR – Climb Trade

BCA – Advanced Concepts | BR&T – Platform Performance Technology

PERFORMANCE SUMMARY

Refined SUGAR – Climb Trade

Product Development Study

Typical Long Range Rules
200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		Meet SUGAR Free Climb Performance	Relax Climb Requirement
PASSENGERS / CLASS		154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	139,800	139,700
MAX LANDING WEIGHT	LB	131,500	131,800
MAX ZERO FUEL WEIGHT	LB	123,500	123,800
OPERATING EMPTY WEIGHT	LB	77,500	77,800
FUEL CAPACITY REQ	USG	5,582	5,512
ENGINE MODEL		Scaled gFan	Scaled gFan
FAN DIAMETER	IN	68	66
BOEING EQUIVLENT THRUST (BET)	LB	16,200	15,700
WING AREA / SPAN	FT^2 / FT	1367 / 126	1440 / 129
ASPECT RATIO (EFFECTIVE)		11.63	11.63
OPTIMUM CL		0.659	0.654
CRUISE L/D @ OPT CL		21.639	21.981
DESIGN MISSION RANGE	NMI	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	39,100	38,800
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	24 / 152	29 / 182
OPTIMUM ALTITUDE (MTOW, ISA)	FT	37,400	38,400
BUFFET ICAC (MTOW, ISA)	FT	44,100	45,200
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,190	8,190
APPROACH SPEED (MLW)	KT	118	115
BLOCK FUEL / SEAT (900 NMI)	LB	52.08 (Base)	51.53 (-1.1%)

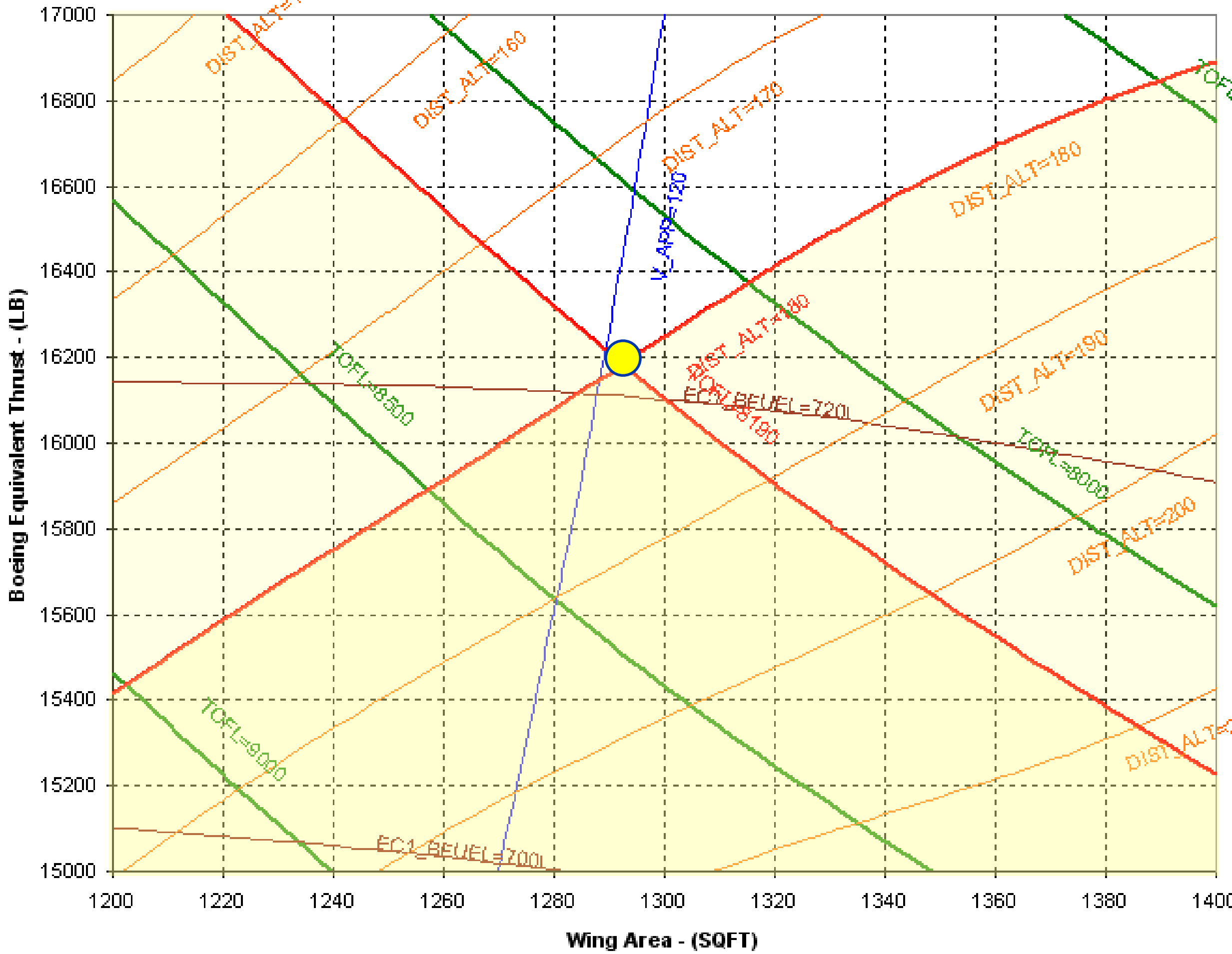
Relaxing climb time requirement allows minor fuel burn improvement

SUGAR High – Sizing

SUGAR High
[Airplane: 765-095, Engine: Gfan+]

Product Development Study

This is the sizing plot for SUGAR High with the reduced wing weight. The final report will contain the SUGAR High point design sizing chart.



Notes:
Time: 09/17/09 : 08:52:47
Job Number: DS-2009-022
Analyst: Conlin

Design Space Data Sheet: [Sheet10]
Plot Data Sheet: [Sheet12]

Fixed Variables:
Aspect Ratio = 26.936306
No. Passengers = 154

Range Requirement: 3500 nmi

Takeoff Field length Conditions:
Altitude: 0 ft
Temperature: 86 degF

Ceiling Conditions:
Temperature: 0 Delta ISA C

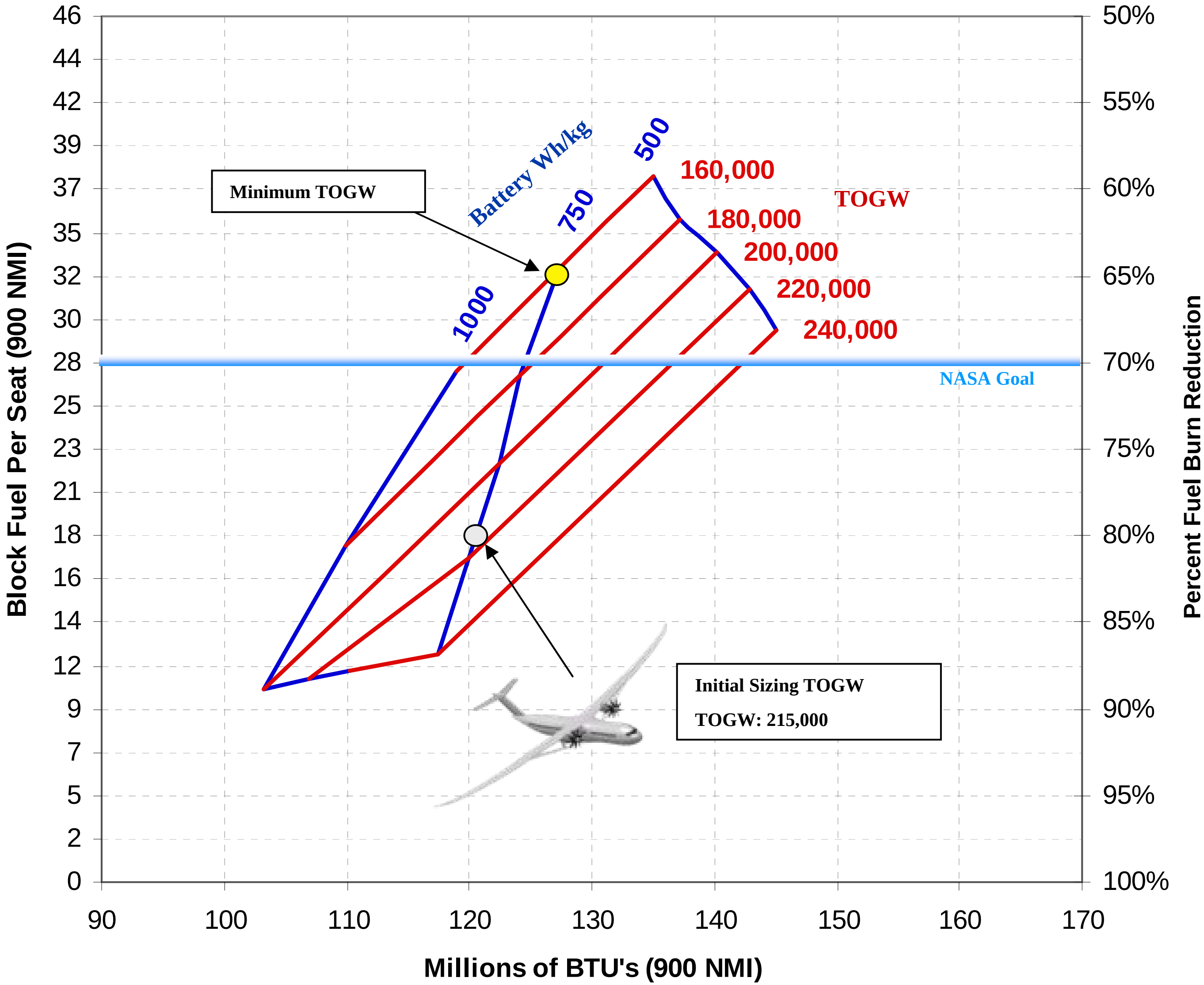
Climb Conditions:
Temperature: 15 Delta ISA C

Fuel Density: 6.50 lb/usg

SUGAR Volt– Opportunities – Open Fan

BCA – Advanced Concepts

BR&T – Platform Performance Technology



SUGAR Volt Trades – Open Fan Power Usage

PERFORMANCE SUMMARY

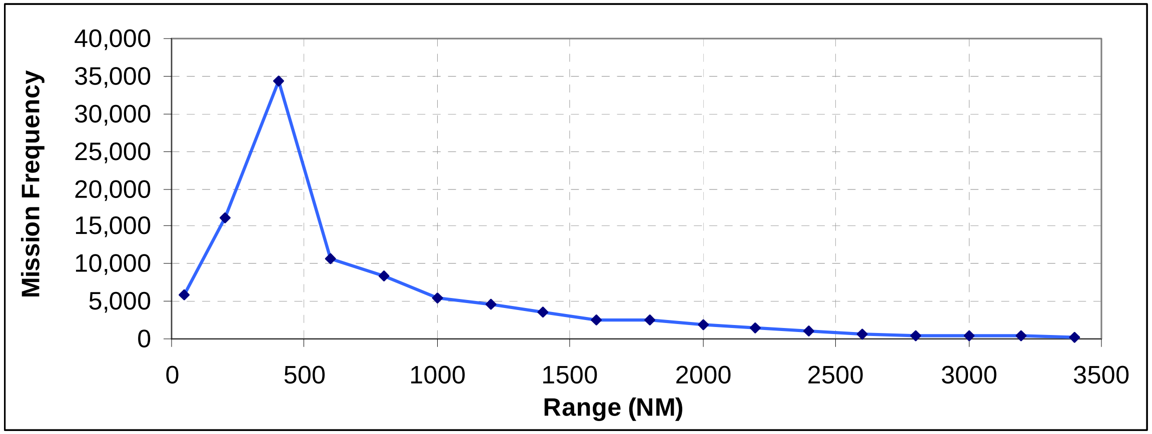
SUGAR Volt – Open Fan Power Trade

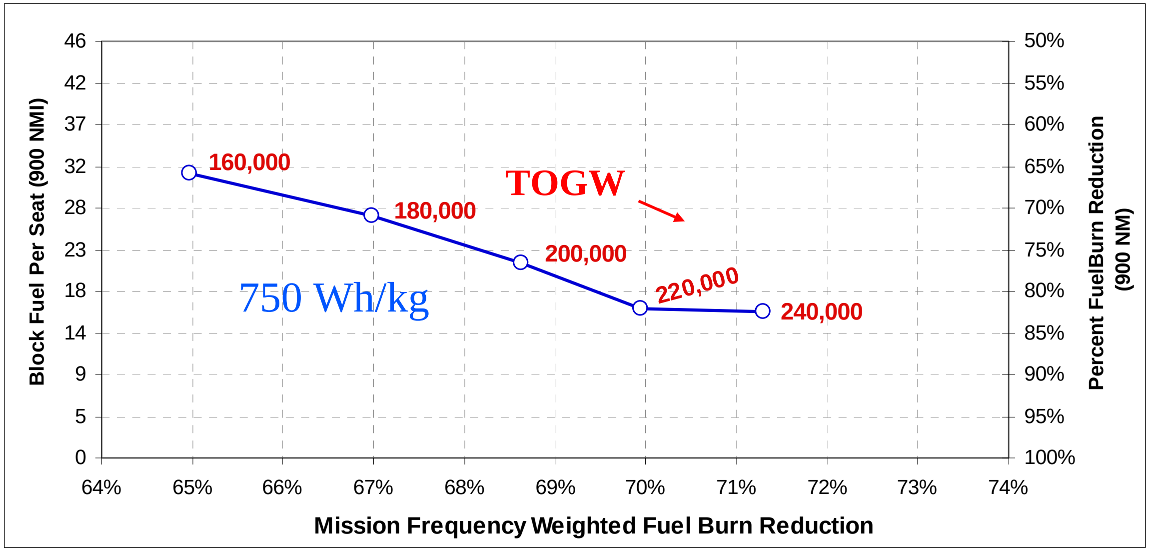
Product Development Study

200 lb / passenger
Standard Day
Alternate C.G. Performance

MODEL Sizing Level		No Electric Systems	SUGAR Volt 0 lb Battery	1,250 hp 9,150 lb Battery	2,500 hp 16,700 lb Battery	3750 hp 24,250 lb Battery
PASSENGERS / CLASS		154 / Dual	154 / Dual	154 / Dual	154 / Dual	154 / Dual
MAX TAKEOFF WEIGHT	LB	140,100	159,200	159,200	159,200	159,200
MAX LANDING WEIGHT	LB	136,000	155,500	155,500	155,500	155,500
MAX ZERO FUEL WEIGHT	LB	128,000	147,500	147,500	147,500	147,500
OPERATING EMPTY WEIGHT	LB	82,000	101,500	101,500	101,500	101,500
FUEL CAPACITY REQ	USG	4,928	4,854	4,854	4,854	4,854
ENGINE MODEL		Scaled gFan+	Scaled hFan Open Fan	Scaled hFan Open Fan	Scaled hFan Open Fan	Scaled hFan Open Fan
FAN DIAMETER	IN	78	~144	~144	~144	~144
BOEING EQUIVLENT THRUST (BET)	LB	16,200	17,600	17,600	17,600	17,600
WING AREA / SPAN	FT^2 / FT	1292 / 187	1558 / 205	1558 / 205	1558 / 205	1558 / 205
ASPECT RATIO (EFFECTIVE)		26.94	26.94	26.94	26.94	26.94
OPTIMUM CL		0.865	0.827	0.827	0.827	0.827
CRUISE L/D @ OPT CL		24.161	25.457	25.457	25.457	25.457
DESIGN MISSION RANGE	NMI	3,500	3,500	3,500	3,500	3,500
PERFORMANCE CRUISE MACH		0.70	0.70	0.70	0.70	0.70
LONG RANGE CRUISE MACH (LRC)		0.70	0.70	0.70	0.70	0.70
THRUST ICAC (MTOW, ISA)	FT	42,900	42,900	42,900	42,900	42,900
TIME / DIST (MTOW, 35k FT, ISA)	NMI / NMI	28 / 181	29 / 179	29 / 179	29 / 179	29 / 179
OPTIMUM ALTITUDE (MTOW, ISA)	FT	41,900	42,200	42,200	42,200	42,200
BUFFET ICAC (MTOW, ISA)	FT	42,900	44,100	44,100	44,100	44,100
TOFL (MTOW, SEA LEVEL, 86 DEG F)	FT	8,150	8,190	8,190	8,190	8,190
APPROACH SPEED (MLW)	KT	120	117	117	117	117
TAKEOFF WEIGHT REQUIRED (900 NMI)	LB	123,000	142,500	150,600	157,400	164,300
OPERATING EMPTY WEIGHT (900 NMI)	LB	82,000	101,500	110,700	118,200	125,800
BLOCK FUEL / SEAT (900 NMI)	LB	46.78 (Base)	46.82 (+0.09%)	39.12 (-16.4%)	34.19 (-26.9%)	29.72 (-36.5%)

SUGAR Volt– Opportunities





- **This mission weighted fuel savings are slightly worse than the 900 NM savings**
- **Slightly higher TOGW allows for 70% fuel burn reduction over an average of existing missions. However, due to the increase in short-range efficiency, different aircraft may be used for longer ranges**

Segment Fuel Burn (900 NMI)

	SUGAR Free	Refined SUGAR	SUGAR High	SUGAR Volt	SUGAR Ray
Taxi-Out	400	67	62	62	62
Takeoff / Climbout	498	382	394	493	492
Climb	3,762	2,212	2,127	1,521	2,561
Cruise	7,523	4,130	3,497	1,812	3,473
Descent	473	889	867	1,025	1,240
Loiter	1,091	-	-	-	-
Approach / Landing	225	190	195	232	228
Taxi-In	250	67	62	62	62
Total	14,222	7,937	7,204	5,207	8,118

Airport Fleet Projections

- **Project Fleet Mix to out year (2030) and define aircraft classes and # daily events of each class at average airport**
- **Determine Noise Power Distance (NPD) for each aircraft type**
  - Based on experience, judgment, and available data
- **Increase fleet mix size (number of events) to account for increase in capacity for a realistic out year (e.g. 2055) containing a large # of N+3 concepts**

and

- **Use 2008, 2030, 2055 capacity with 100% N+3 replacement of older aircraft**

Number of Flights per Month and Aircraft Categories

BCA – Advanced Concepts	BR&T – Platform Performance Technology

Future Scenario 2008

%	Number	Category	Type
33%	235.0	Medium N/N-1	737-800
0%	0.0	Medium N+1/N+2	New
0%	0.0	Medium N+3	SUGAR Ray
67%	482.1	Regional N-1	Typical 2008 Regional
0%	0.0	Regional N	New
0%	0.0	Reqional N+3	2030 Regional
100%	717.1	Total	Growth from 2008 0%
			Growth Rate **1.8%**

Future Scenario 2030

%	Number	Category	Type
31%	334.1	Medium N/N-1	737-800
22%	232.1	Medium N+1/N+2	New
0%	0.0	Medium N+3	SUGAR Ray
28%	302.3	Regional N-1	Typical 2008 Regional
18%	193.3	Regional N	New
0%	0.0	Reqional N+3	2030 Regional
100%	1061.8	Total	Growth from 2008 48%

Future Scenario 2055

%	Number	Category	Type
0%	0.0	Medium N/N-1	737-800
31%	512.8	Medium N+1/N+2	New
31%	512.8	Medium N+3	SUGAR Ray
0%	0.0	Regional N-1	Typical 2008 Regional
16%	259.2	Regional N	New
22%	372.9	Reqional N+3	2030 Regional
100%	1657.7	Total	Growth from 2008 131%

2008 N+3 Only

%	Number	Category	Type
0%	0.0	Medium N/N-1	737-800
0%	0.0	Medium N+1/N+2	New
33%	235.0	Medium N+3	SUGAR Ray
0%	0.0	Regional N-1	Typical 2008 Regional
0%	0.0	Regional N	New
67%	482.1	Reqional N+3	2030 Regional
100%	717.1	Total	

2030 N+3 Only

%	Number	Category	Type
0%	0.0	Medium N/N-1	737-800
0%	0.0	Medium N+1/N+2	New
53%	566.2	Medium N+3	SUGAR Ray
0%	0.0	Regional N-1	Typical 2008 Regional
0%	0.0	Regional N	New
47%	495.5	Reqional N+3	2030 Regional
100%	1061.8	Total	Growth from 2008 48%

2055 N+3 Only

%	Number	Category	Type
0%	0.0	Medium N/N-1	737-800
0%	0.0	Medium N+1/N+2	New
97%	1025.7	Medium N+3	SUGAR Ray
0%	0.0	Regional N-1	Typical 2008 Regional
0%	0.0	Regional N	New
60%	632.1	Reqional N+3	2030 Regional
156%	1657.7	Total	Growth from 2008 131%

Number of flights and aircraft categories (Regional/Medium & N/ N+1/N+2/N+3) derived from future scenario

Metroplex Compatibility Discussion

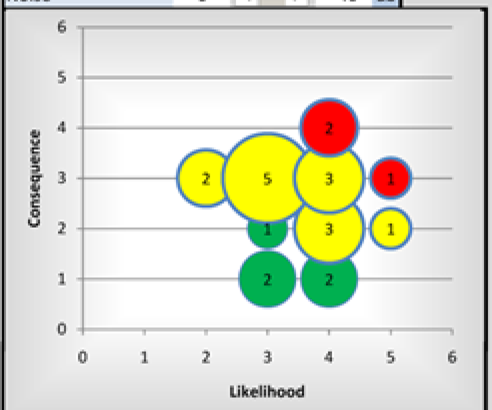
- **ACN/PCN pavement loading at weaker taxiways and runways**
- **Gate constraints on spans**
- **Taxi way constraints on wing span, turn radius, and gear width - can't run off the end of the pavement….**
- **Interference with lights, parallel taxi ways, aircraft on runways, bridges, signage, and other airport obstacles**
- **TOFL, LFL**
- **TOFL, LFL in non standard conditions - high, hot, cross winds, obstacles, climb gradients, noise constraints/profiles**
- **Compability with limited infrastructure such as airstairs, refueling trucks, no special loaders, catering, maintenance infrastructure etc**
- **Wing fold time and stability in stowed position with winds, taxing on rough surfaces**

SUGAR High - Fuel Burn Goal

Concept
SUGAR High

NASA Goals

Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	0	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Technology
1	NextGen ATM Capable
2	Natural Laminar Flow
3	Very high bypass ratio turbofan with 2030 engine technologies
4	Low Drag Strut (no interference, laminar flow in NLF)
5	Very high bypass ratio turbofan with advanced engine tech.
6	Bundle together advanced engine materials
7	Bundle together advanced material technologies
8	Advanced Supercritical Airfoil
9	Fuselage & Wing Riblets
10	Bundle together advanced subsystem technologies
11	Active/Passive Aeroelastic Response for Load Control
12	Adv. Lightweight High Lift Systems
13	Bundle together multi-functional structures technologies
14	Relaxed Static Stability & Increased CLMax Empennage
15	Low Interference Nacelles
16	
17	
18	Bundle together advanced structures technologies
19	Additional advanced passive treatments
20	Airframe acoustic technologies
21	Active noise control/fluidics
22	Lightweight Wing Folds
23	
24	
25	
26	

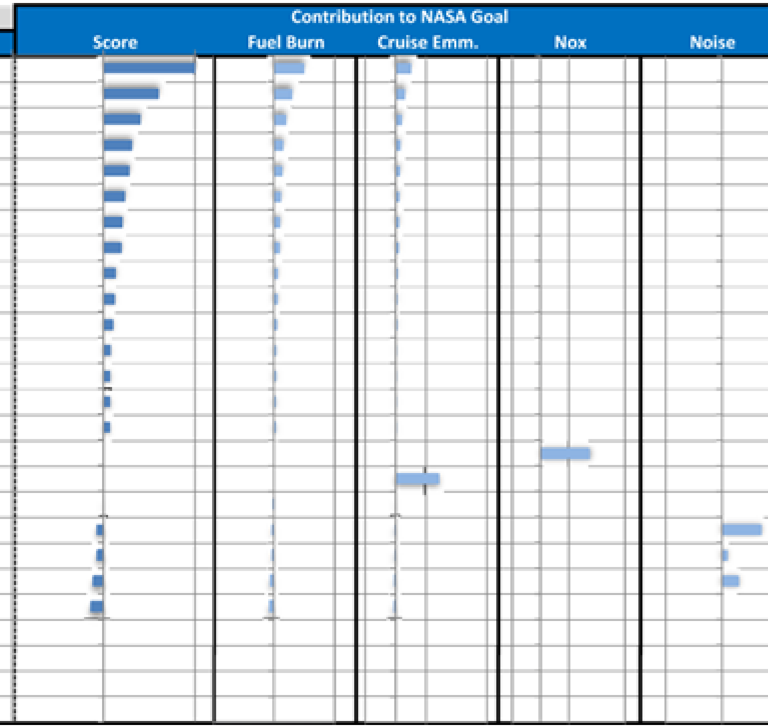


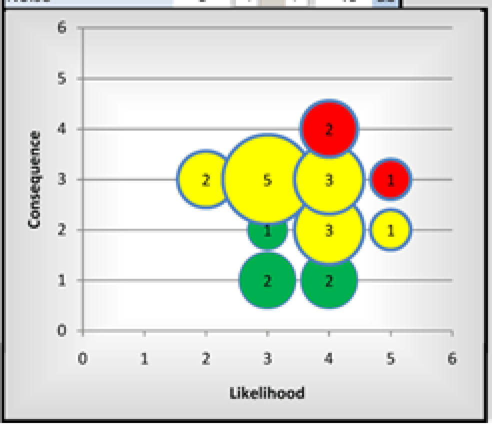
Figure 7.9 – SUGAR High Technology Ranking for Fuel Burn Goal

SUGAR High - NOx Reduction Goal

BCA – Advanced Concepts | BR&T – Platform Performance Technology

Concept
SUGAR High

NASA Goals		
Goal	Importance	Value
Fuel Burn	0	-70 %
Cruise Emissions	0	-70 %
NoX	1	-75 %
Noise	0	-40 db



Rank	Technology	Score	Contribution to NASA Goal: Fuel Burn	Cruise Emm.	Nox	Noise
1	TAPS & Next Generation TAPS					
2						
3						
4						
5						
6						
7						
8						
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25						
26						

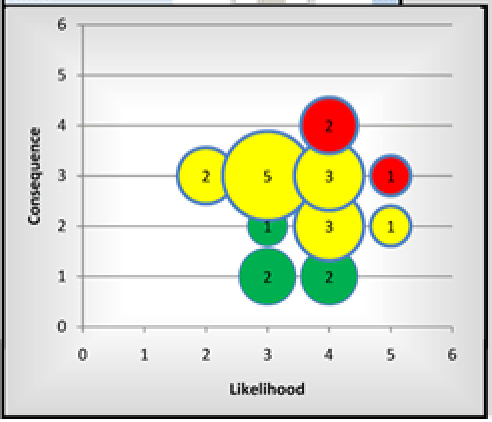
Figure 7.11 – SUGAR High Technology Ranking for NOx Reduction Goal

SUGAR High - Noise Reduction Goal

BOEING

Concept
SUGAR High

NASA Goals			
Goal	Importance	Value	
Fuel Burn	0	-70	%
Cruise Emissions	0	-70	%
NoX	0	-75	%
Noise	1	-40	db



Rank	Technology	Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	Additional advanced passive treatments					
2	Active noise control/fluidics					
3	Airframe acoustic technologies					
4						
5						
6						
7						
8						
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25						
26						

(Fuel Burn, Cruise Emm., Nox, Noise: Contribution to NASA Goal)

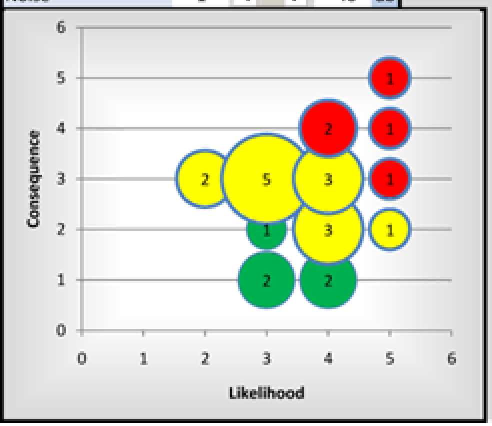
Figure 7.12 – SUGAR High Technology Ranking for Noise Reduction Goal

SUGAR Volt - Noise Reduction Goal

BOEING

Concept
SUGAR Volt

NASA Goals			
Goal	**Importance**	**Value**	
Fuel Burn	0	-70	%
Cruise Emissions	0	-70	%
NoX	0	-75	%
Noise	1	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	Additional advanced passive treatments					
2	Active noise control/fluidics					
3	Airframe acoustic technologies					
4						
5						
6						
7						
8						
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Figure 7.17 – SUGAR Volt Technology Ranking for Noise Reduction Goal

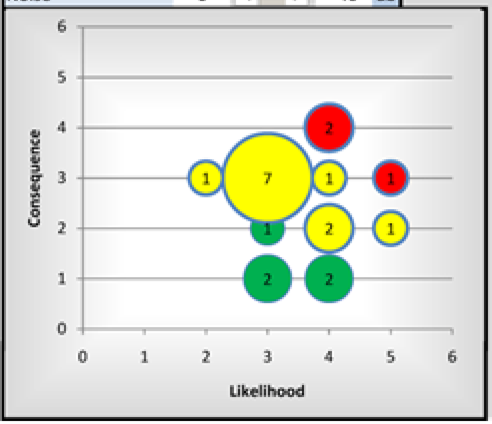
SUGAR Ray - Fuel Burn Reduction

BOEING

Concept
SUGAR Ray

NASA Goals

Goal	Importance	Value	
Fuel Burn	1	-70	%
Cruise Emissions	0	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	NextGen ATM Capable					
2	Very high bypass ratio turbofan with advanced engine tech.					
3	Natural Laminar Flow					
4	Very high bypass ratio turbofan with 2030 engine technologies					
5	Bundle together advanced engine materials					
6	Fuselage & Wing Riblets					
7	Bundle together advanced material technologies					
8	Open Fan					
9	Active/Passive Aeroelastic Response for Load Control					
10	Low Interference Nacelles					
11	Relaxed Static Stability & Increased CLMax Empennage					
12	Bundle together multi-functional structures technologies					
13						
14						
15						
16	Bundle together advanced structures technologies					
17	Additional advanced passive treatments					
18	Airframe acoustic technologies					
19	Lightweight Wing Folds					
20	Active noise control/fluidics					
21						
22						
23						
24						
25						
26						

Figure 7.19 – SUGAR Ray Technology Ranking for Fuel Burn Reduction

SUGAR Ray - NOx Reduction Goal

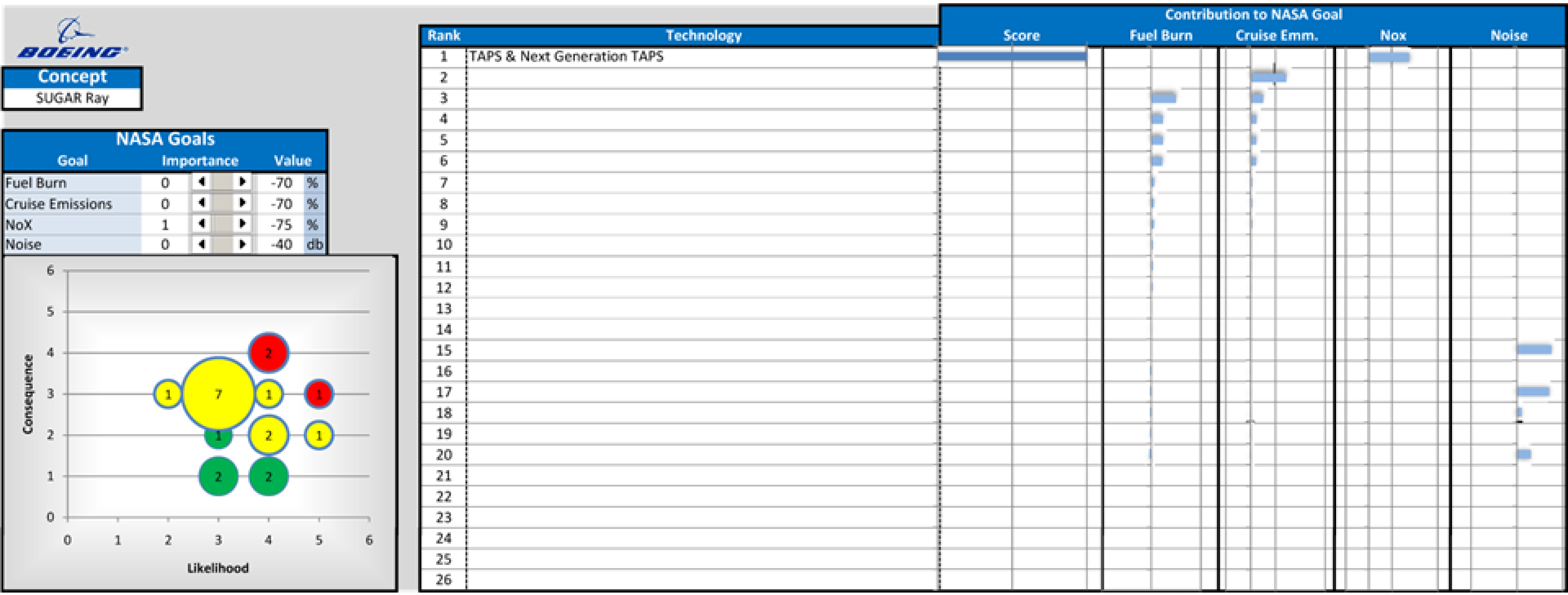


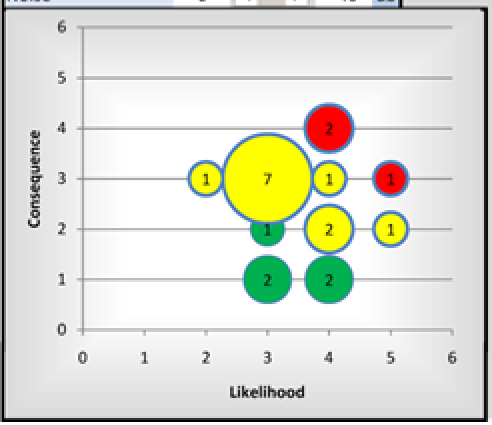
Figure 7.21 – SUGAR Ray Technology Ranking for NOx Reduction Goal

SUGAR Ray - Cruise Emissions

Concept
SUGAR Ray

NASA Goals

Goal	Importance	Value	
Fuel Burn	0	-70	%
Cruise Emissions	1	-70	%
NoX	0	-75	%
Noise	0	-40	db



Rank	Technology	Contribution to NASA Goal: Score	Fuel Burn	Cruise Emm.	Nox	Noise
1	Low sulfur Jet-A, Synthetic or Biofuels					
2	NextGen ATM Capable					
3	Very high bypass ratio turbofan with advanced engine tech.					
4	Natural Laminar Flow					
5	Very high bypass ratio turbofan with 2030 engine technologies					
6	Bundle together advanced engine materials					
7	Fuselage & Wing Riblets					
8	Bundle together advanced material technologies					
9	Open Fan					
10	Active/Passive Aeroelastic Response for Load Control					
11	Low Interference Nacelles					
12	Relaxed Static Stability & Increased CLMax Empennage					
13	Bundle together multi-functional structures technologies					
14						
15						
16	Bundle together advanced structures technologies					
17	Additional advanced passive treatments					
18	Airframe acoustic technologies					
19	Lightweight Wing Folds					
20	Active noise control/fluidics					
21						
22						
23						
24						
25						
26						

Figure 7.20 – SUGAR Ray Technology Ranking for Cruise Emissions

Summary – Performance Results

- **Refined SUGAR results indicate a 44%-54% reduction in fuel burn compared to the SUGAR Free baseline on a 900 nm mission**
- **SUGAR High results indicate a 39%-58% reduction in fuel burn**
- **LTO NOx Emissions can be reduced by 58%-72% compared CAEP/6**
- **TOFL of 5,000 ft possible for 900 nm mission fuel loads**
- **SUGAR Volt architecture enables additional performance potential**
  - A 63%-90% reduction in fuel burn, a 56% reduction in total energy use, a LTO emissions reduction of 79%-89%, and additional noise and TOFL flexibility
- **SUGAR Ray HWB has significantly lower noise due to airframe shielding, but for fuel burn does not out-perform the conventional configuration in this study**

Note: Quoted %'s are Point Design & Best Trade/Opportunity

Summary (1)

- The future scenario is based on a 20-year current market outlook process that Boeing has used for the last 40 years.
- The future scenario was used to establish baseline, reference, and advanced aircraft in three size classes (regional, medium, and large) for the 2008-2055 timeframe.
- Also derived from the future scenario were the payload, speed, design range, and average range for each of the size classes.
- For this study, it was decided to concentrate design and analysis resources on a medium size aircraft carrying 154 passengers to a maximum range of 3500 nm.

Summary (2)

- **A concept selection workshop was held at Georgia Tech to discuss and select advanced concept configurations and enabling propulsion technologies. From the workshop and post-workshop discussions, the following five configurations were selected for detailed analysis:**
  1. SUGAR Free – Current technology, similar to 737 class aircraft. Used as Baseline for performance comparisons.
  2. Refined SUGAR – Basic conventional configuration with estimated 2030-2035 N+3 technologies, including improved NEXTGEN air traffic control mission efficiency. Includes "gFan" turbofan engine from GE.
  3. SUGAR High – High span strut-braced wing configuration with advanced 2030-2035 N+3 technologies. Assumes significant technology development beyond the technologies in the Refined SUGAR concept. "gFan+" turbofan and open fan propulsion options supplied by GE.
  4. SUGAR Volt – Builds off of SUGAR High configuration to add electric propulsion technologies. Initially considered a variety of electric-propulsion architectures (Battery electric only, fuel-cell gas turbine hybrid, battery electric gas turbine hybrid), but Boeing point-of-departure sizing analysis and GE analysis led to selection of battery gas turbine hybrid propulsion architecture. "hFan" turbofan-electric hybrid engine data developed by GE.
  5. SUGAR Ray – A HWB configuration that uses a similar suite of advanced technologies as the SUGAR High. Primary design emphasis is on reducing aircraft noise, while maintaining performance similar to the SUGAR High.

Summary (3)

- **Technology and system experts were engaged to establish technology suites for each of the five configurations.**
- **Technologies were selected in four categories:**
  - Aero
  - Structural
  - Subsystem
  - Propulsion
- **Refined SUGAR technologies assume a "business as usual" technology development between now and 2030-2035.**
- **SUGAR High, SUGAR Volt, and SUGAR Ray assume significant additional focused development of technologies for these aircraft.**

Summary (4)

- **To begin the analysis and sizing process, a point-of-departure sizing analysis was conducted.**
- **This conceptual analysis provided initial sizing information to start the more detailed design and analysis process.**
- **These results established “goal” performance levels for the configurations and their technologies.**
- **For the SUGAR Volt, the point-of-departure analysis included a trade study to establish required battery technology levels and to compare various electric propulsion architectures.**
- **Ultimately a battery electric, gas turbine hybrid propulsion architecture was selected.**
- **These results were presented at the 6-month review, and for the average 900 nm mission, showed approximately:**
  - 50% reduction in fuel burn for the Refined SUGAR
  - 58% reduction for the SUGAR High
  - Up to a 90% reduction in fuel used for the SUGAR Volt

Summary (5)

- **Detailed analysis and sizing began when the point-of-departure results were used to draw each configuration. From this geometry model, aerodynamics and mass properties analyses were conducted on the as-drawn configuration. The point-of-departure results were also used to develop an initial size for the engines. Then a mission performance analysis was used to resize the as-drawn aircraft to meet all constraints. In some cases, constraints were adjusted as part of a requirements analysis trade study. Detailed analysis and sizing was completed for all configurations.**
  - The Refined SUGAR results indicate a 44% reduction in fuel burn compared to the SUGAR Free baseline on a 900nm mission. Opportunities have been identified for up to a 54% fuel burn reduction by using the gFan+ engine and a higher span wing. NOx emissions were reduced to 42% of CAEP 6 levels by using an advanced combustor. CO_2 emissions can be reduced by 72% by adding biofuels to the other technologies. Noise is reduced by 16 db. Design takeoff distances of 8200 ft can be achieved at full weight or reduced to 5500 ft or less for the average mission fuel load.
  - The SUGAR High results indicate a 39% reduction in fuel burn compared to the SUGAR Free baseline on a 900nm mission. Opportunities for wing weight reduction and aerodynamic improvements have been identified for up to a 58% fuel burn reduction. NOx emissions were reduced to 28% of CAEP 6 levels by using an advanced combustor. CO_2 emissions can be reduced by 69% by adding biofuels to the other technologies. Noise is reduced by 22 db. Design takeoff distances of 8200 ft can be achieved at full weight or reduced to 6000 ft or less for the average mission fuel load.
  - The SUGAR Volt results indicate a 63% reduction in fuel burn compared to the SUGAR Free baseline on a 900nm mission. Opportunities have been identified for up to a 90% fuel burn reduction through greater electric usage. If total energy usage (fuel plus electricity) is considered, a 56% reduction is achieved. NOx emissions were reduced to 21% of CAEP 6 levels by using an advanced combustor with a potential for even greater reductions (to 11%) by optimizing electric motor usage. CO_2 emissions can be reduced by 81% by adding biofuels to the other technologies. Noise is reduced by at least 22 db, with more reduction available by optimizing the electric motor usage during takeoff and climb-out. Design takeoff distances of 8200 ft can be achieved at full weight or reduced to 4000-5200 ft for the average mission takeoff weight.
  - The SUGAR Ray results indicate a 43% reduction in fuel burn compared to the SUGAR Free baseline on a 900nm mission. NOx emissions were reduced to 28% of CAEP 6 levels. CO_2 emissions can be reduced by 75% by adding biofuels to the other technologies. Due to additional airframe shielding benefits, noise is reduced by 37 db.

Summary (6)

- **The team conducted a Technology Workshop in November 2009. At this workshop, the team accelerated the final technology roadmap prioritization and risk assessment.**
- **The risk associated with the technology suites for each configuration has been assessed and the relationship between each technology (or technology group) and each NASA goal has been quantified.**
- **Development roadmaps for each technology (or technology group) have been established.**

Summary (7)

- **A wide range of technologies contribute to substantial fuel burn reduction.**
- **Biofuels are a large contributor to reducing greenhouse gas emissions.**
- **Advanced combustor technology is key to reducing NOx emissions.**
- **Reducing aircraft noise requires an array of engine and airframe noise technologies.**

Summary (8)

- **Finally, the results of the configuration assessment and technology analysis processes were used to develop recommendations for Phase 2 work.**

Point of Departure – Initial Sizing

- **2030 Electric Trade Configuration (Sugar Volt)**
  - Hybrid (gas turbine and battery)

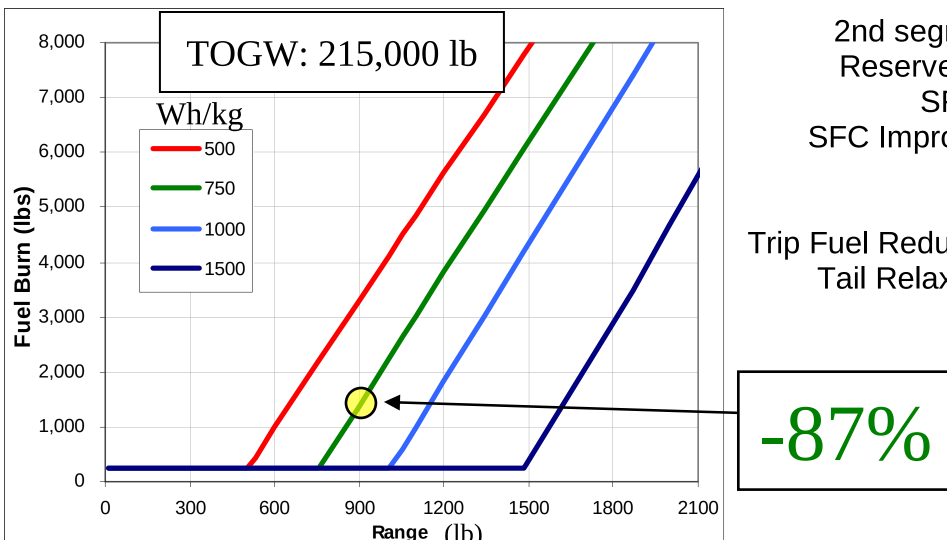
Conditions and Assumptions

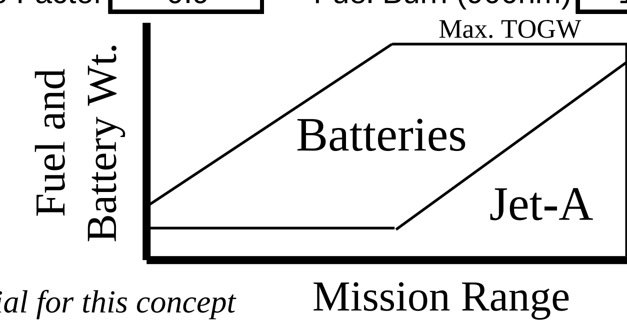
Mach	0.65
Max Range (nm)	3,500
Range for Fuel Burn	900
TOFL (sea level):	7,000
ICA	42,207
Strut?	y
Climb at ICA (fpm)	300
Carbon Wt redctn factor	0.9
Cl takeoff	2.4
2nd segment climb (Cl)	1.4
Reserves, N + ("0","3")	3.0
SFC Hit at Divert	50%
SFC Improv over CFM56	25%
Laminar Credit	y
Riblet Credit	y
Trip Fuel Reduction (Routing)	5%
Tail Relaxed Size Factor	0.9

Vehicle Specifications

AR	24.0
Sref (ft^2)	2,473
Span (ft)	244
Root t/c	0.130
Tip t/c	0.085
Ct/Cr	0.18
Cruise Cl	0.833
A (sweep)	20.00
L/D	32.43
ICA	42,207
Battery Weight (lbs)	26,314
Batt Wh/Kg	750

TOGW	215,000
Fuel Burn (900nm)	1,490





Pre-existing and new intellectual property potential for this concept