Hybrid-Electric Propulsion

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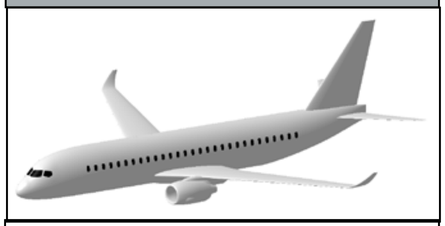
Boeing N+3 Subsonic Ultra Green Airplane Research

Concept Selections and Initial Performance

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

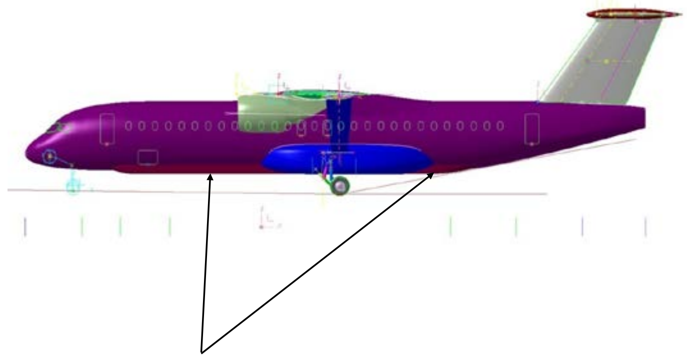
Up to -88% Fuel Burn

N+3
Reduced Noise HWB
“SUGAR Ray”

Not analyzed

SUGAR Volt is Derived from SUGAR High

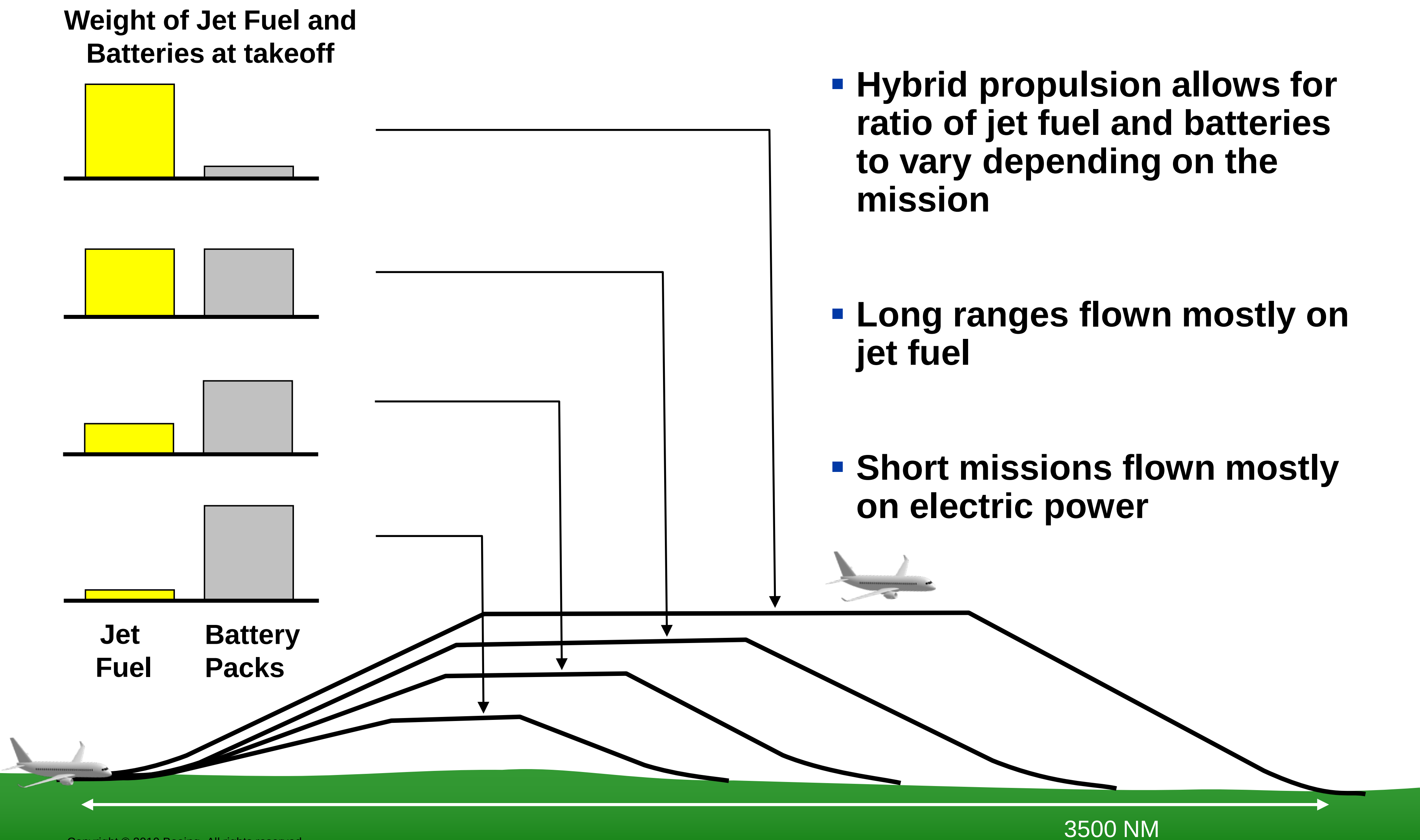
- **Same as SUGAR High Except:**
  - Propulsion system weight increased to 10,475 lbs
  - Added battery weight dependent on range (20,900 lbs at 900 nmi for base airplane)
  - Battery mounting weight 5,000 lbs
  - Wire weight 1,000 lbs
  - 2.5 drag counts for battery fairing
  - Low wing weight version of SUGAR High wing



Removable Modular Battery Pack

- **Note that SUGAR Volt hybrid electric engine and power system could be applied to other configurations (Refined SUGAR or SUGAR Ray)**

Battery and Jet Fuel Loading



- 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 - Sizing

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

40% Reduction from Sugar High

Electric/Hybrid Electric - What is Next?

- **Everyone will keep watching battery technology development**
  - What will be the best chemistries/technologies?
  - Will trends continue progression or will they break?
- **Some will jump in and do something now!**
  - Technology demonstrators
  - Short range general aviation applications
  - Rules, regulations, and certification development
- **Battery technology and what we do now will determine the future of electric aircraft**

Technology Not Yet Ready for Electric/Hybrid Airliners – But be Watchful!

Hybrid-Electric Demonstrator Aircraft

Hybrid-Electric Power System Schematic

Fuel tank
Fuel pump & throttle servo
Honda GX160 (7 kW)
Reduction drive 2.6:1
Throttles
Mode
Power Controller
Joby JM1 (10 kW)
Battery pack 1 8 x 40 Ahr cells
BMS 1
Battery pack 2 8 x 40 Ahr cells
BMS 2

ICE=Internal Combustion Engine

Parallel electric / fuel hybrid

- **ICE + Elec. motor**
- **ICE only**
- **ICE + Regen.**
- **Elec. motor only**

Advantages of Near Term Demonstrations

- **Design team gains and maintains needed experience**
  - Lessons learned for design and optimization
- **Public acceptance of electric aircraft**
- **Interactions with government rule makers**
- **Unexpected technical advances and improvements**
- **Creates confidence in team and technology for future investment**
- **Maintains public and industry interest**
- **Inspires students (future engineers and leaders)**
- **An opportunity to leverage resources and share knowledge across a wide range of people and organizations**

Electric/Hybrid Electric Aircraft

- **Recent studies show great promise for future electric/hybrid electric aircraft**
  - Reduced environmental impact
  - Reduced energy cost & increased flexibility
  - Reduced system complexity
- **But with challenges:**
  - Dirty electric grids
  - Heavy batteries and systems
  - Safety and certification
  - Business case and technology investment
  - How do small technology demonstrations support a larger future aircraft?