Designing the Aircraft of the Future

Centennial Symposium – 24 Oct 12
Air Transportation Trends

Passenger-Kilometers (billions)

Sources: ICAO Traffic Data, The World Bank

North America
Asia and Pacific
Europe
Rest of world
The Passenger Jet

Relative to an automobile, a modern jet is . . .

- 100× safer per passenger-mile
- comparable in fuel burn per passenger-mile
Progress (?)

Wright Flyer  
Boeing 707  
Boeing 787

1903 . . . 55 years . . . 1958 . . . 55 years . . . 2013
Progress (!)

Wright Flyer

Boeing 707

Boeing 787

1903 . . . 55 years . . . 1958 . . . 55 years . . . 2013

45 Seat-mpg

120 Seat-mpg
**Progress (!)**

Wright Flyer  
Boeing 707  
Boeing 787

1903 ... 55 years ... 1958 ... 55 years ... 2013

**Cost per Seat-Mile**

Source: Airlines for America
First-Law Model of Airline Business

Fuel Energy $$\rightarrow$$ Do useful stuff $$\rightarrow$$ Heat to Atmosphere
Energy Flow in Jet Transports

Fuel Energy $$$

Do useful stuff

53 shaft power

engine core 82%

65 ideal work

Brayton cycle 65%

100

12 BL heating

35 heat in core jet

53

heat

47

shaft power

100

Heat to Atmosphere

100
Energy Flow in Jet Transports

Fuel Energy $$$

100

Brayton cycle 65%

65

ideal work

engine core 82%

12

BL heating

5

jet power

fan+duct 89%

48

jet power

fan jet 83%

40

propulsive power

8

jet KE

Do useful stuff

100

heat in core jet

35

Heat to Atmosphere

100

13 heat + KE

47 heat

40

propulsive power

40
Energy Flow in Jet Transports

**AIRFRAME**
- Induced power
  - Wing
  - Fuselage
  - Tail
  - Nacelles

**Propulsive Power**
- Fan jet 83%
  - Jet power
- Fan + Duct 89%
  - Jet power
- Engine core 82%
  - Shaft power
- Brayton cycle 65%
  - Ideal work

**Fuel Energy**
- Heat to Atmosphere

**Heat in Core Jet**
- 35%

**Jet KE**
- 8%

**Jet Heating**
- 12%

**Vortex KE**
- 15%

**BL Heating**
- 11%
- 7%
- 4%
- 3%

**Shaft Power**
- 53%
Energy Reductions – Improved Engine Materials

Higher thermal efficiency
Higher core component efficiencies

Airframe
- Induced power
- Wing
- Fuselage
- Tail
- Nacelles

Propulsive power
- Engine core
  - Brayton cycle 65%
  - Ideal work 65%

Jet power
- Fan jet 83%
- Fan + duct 89%
- Jet power 89%
- Shaft power 82%

Jet KE
- Vortex KE 83%
- BL heating 82%

Heat to Atmosphere
- 100
Energy Reductions – Turbofan Technology

Better matching of fan and core
Reduced engine weight

Fuel Energy $$$

Brayton cycle 65%

Heat in core jet

Heat to Atmosphere

100
Energy Reductions – Turbofan Technology

Pratt & Whitney Geared Turbofan (2013)
Energy Reductions – Composites

Airframe energy dissipation roughly scales with weight

**Airframe**
- **induced power**
- **wing**
- **fuselage**
- **tail**
- **nacelles**

**Propulsive power**
- **fan jet 83%**
- **fan+duct 89%**
- **engine core 82%**

**Jet power**
- **jet KE**

**Shaft power**
- **BL heating**

**Ideal work**
- **heat in core jet**

**Fuel Energy $$$**
- **100**

**Brayton cycle 65%**
- **8**
- **5**
- **12**

**Heat to Atmosphere**
- **100**
Energy Reductions – Composites

Boeing 787

www.aviamz.net/aviamz-site-blog
Energy Reductions – Reduced Wetted Area

Boundary layer losses scale roughly with wetted area

Fuel Energy $$$

40
propulsive power

48
fan jet
83%

jet power

53
fan+duct
89%

shaft power

engine core
82%

65
ideal work

100
Brayton cycle
65%

8
jet KE

5
BL heating

12
BL heating

15
vortex KE

11
BL heating

AIRFRAME

induced power

wing

15
BL heating

fuselage

7
BL heating

4
BL heating

3
BL heating

tail

nacelles

fan+duct

11
BL heating

heat in core jet

Heat to Atmosphere

100
Energy Reductions – Reduced Wetted Area

Blended Wing Body
Energy Reductions – Reduced Induced Drag Loss

Via increased span without weight penalty

Airframe

- Induced power
- Wing
- Fuselage
- Tail
- Nacelles

Fan jet 83%
Fan + duct 89%
Engine core 82%
Shaft power
Jet power
Jet KE
Vortex KE
BL heating
Ideal work
Brayton cycle 65%

Fuel energy $$$

Heat to Atmosphere 100

Propulsive power 40
Jet power 48
Shaft power 53
Ideal work 65
Brayton cycle 65
Jet KE 8
Vortex KE 15
BL heating 11
BL heating 7
BL heating 4
BL heating 3
Energy Reductions – Reduced Induced Drag Loss

Boeing/NASA N+3 Truss-Braced Wing
Energy Reductions – Configuration, Integration, BLI

Boundary Layer Ingestion
Integrated engines
Fuselage configuration effects

![Diagram of energy reduction and configuration integration with BLI]

- **Fuel Energy**: $\$\$\$
- **Brayton cycle**: 65%
- **Heat in core jet**: 35%
- **Heat to Atmosphere**: 100%

**AIRFRAME**
- **Induced power**
  - **Wing**: 11
  - **Fuselage**: 7
  - **Tail**: 4
  - **Nacelles**: 3

**Propulsive power**
- **Fan jet**: 83%
- **Jet power**: 48
- **Fan+Duct power**: 53
- ** Shaft power**: 65

**BL heating**
- **JetKE**: 8
- **Vortex KE**: 15
- **Engine core**: 12
- **Ideal work**: 65
Energy Reductions – Configuration, Integration, BLI

MIT/NASA N+3 D8 Concept
D8 Fuel Burn Benefits

737-800
Baseline

D8.2
-33% fuel
Current Tech (+ BLI)

D8.6
-65% fuel
Advanced Tech (2035)
What would you do?