Jim Kroeger
Director, Propulsion Engineering
Honeywell Aerospace

September 6, 2017

ISABE2017
23rd ISABE Conference

THE MAKINGS OF AN ICONIC ENGINE

Honeywell
THE POWER OF CONNECTED

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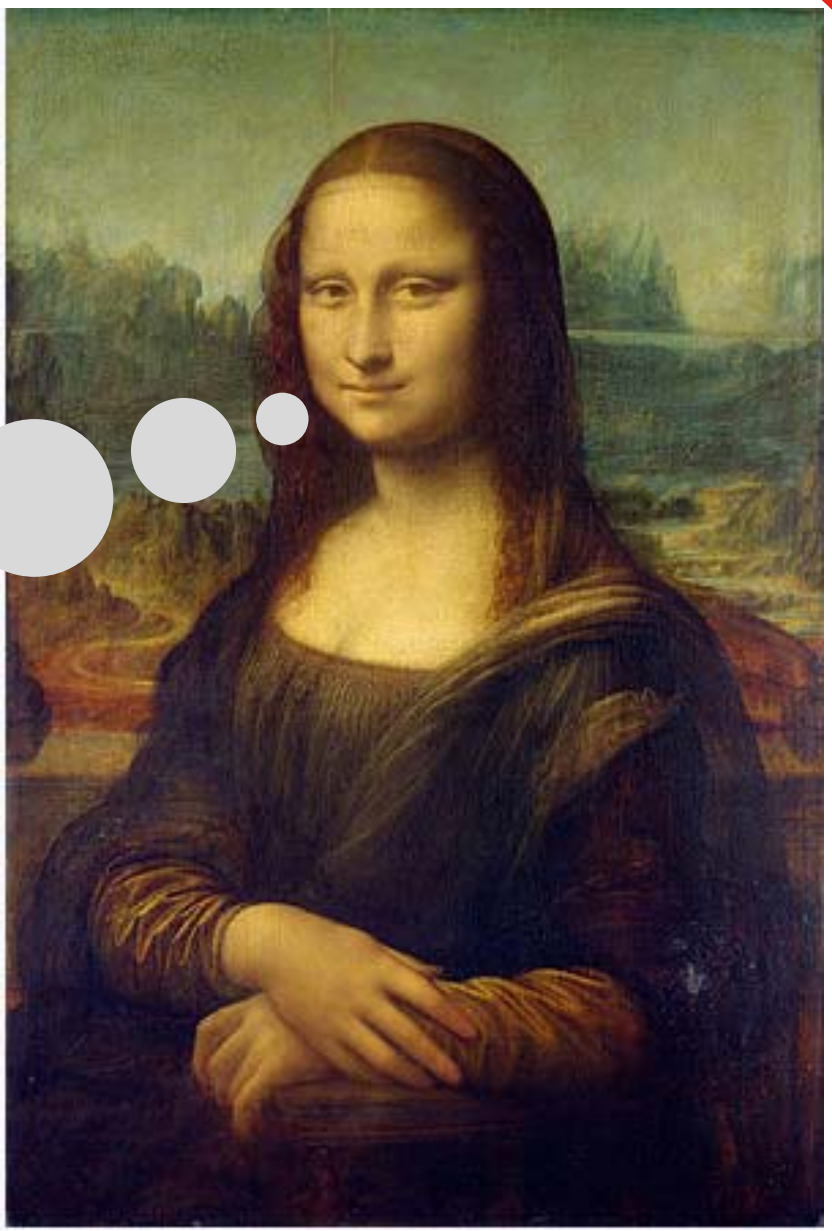
ISABE
take note:

Only a few of your turbine engines will be **ICONIC**, like me!



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Honeywell
THE POWER OF CONNECTED

An Automotive Example . . .

2018

Ford Mustang Deserves Distinction as “ICONIC”

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Not So Timeless Designs…

Ford Pinto's Design Flaws Labeled it a "Failure"

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You Should Aspire to MORE . . .

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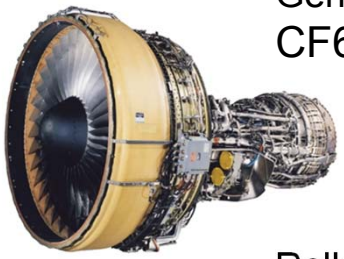
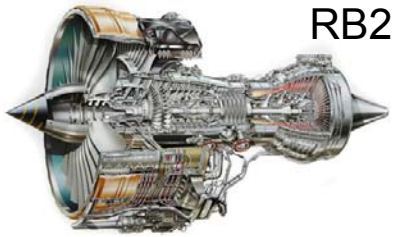
ICONIC Engine Designs . . .

Pratt & Whitney
JT9/PW4000

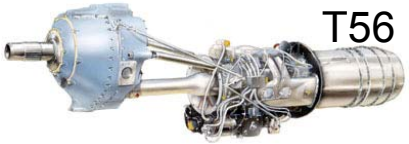


General Electric
CF6



Rolls Royce
RB211/Trent

Honeywell
T55



General Electric
T56

General Electric
T700

Rolls Royce
T63

CFM
CFM56

Pratt & Whitney
PT6

Honeywell
TFE731

- In production >35 years
- Pattern of variants and upgrades
- Highly regarded among users
- Coveted business by parent company

. . . Shape Aviation History

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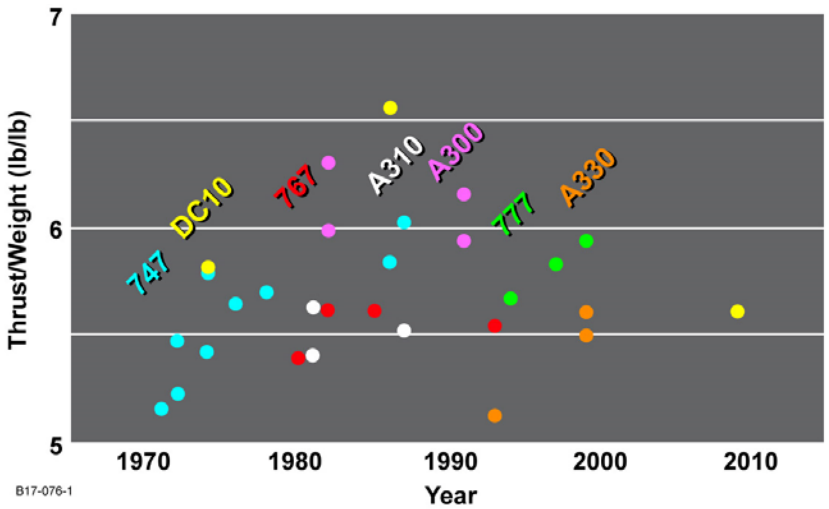
P&W JT9 *(and Successor PW4000) . . .*



- First fielded in 1969
- ~7000 units shipped
- Eight applications, 42 models
- 45,000 to 115,000 lb F_n

. . . Enabled Modern Widebody Transport

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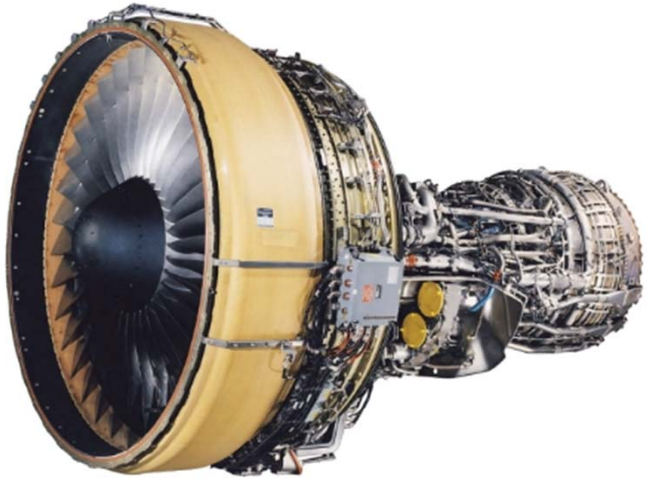
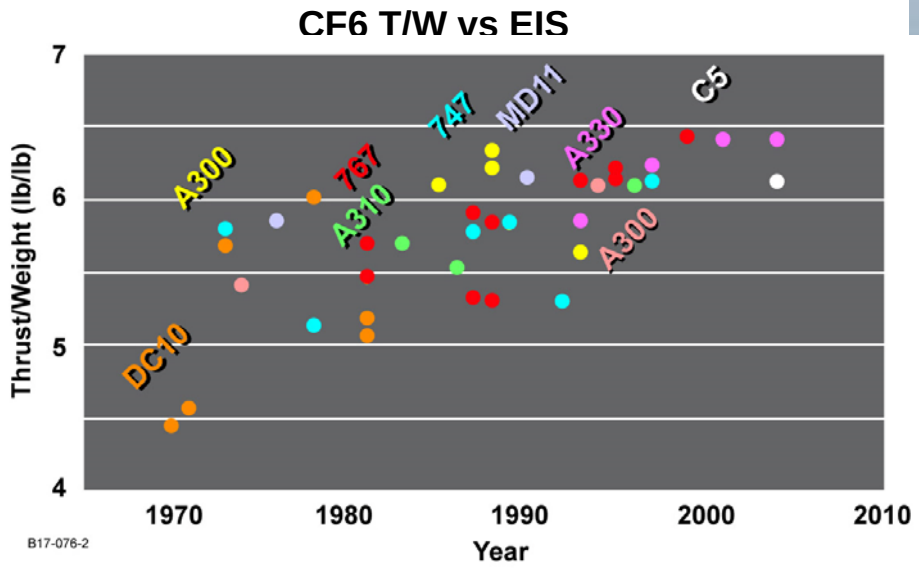
GE CF6 . . .





- First fielded in 1970
- ~6000+ units shipped
- Eight applications, 41 models
- 41,500 to 69,800 lb F_n

Spawned LM2500

. . . Enabled Modern Widebody Transport

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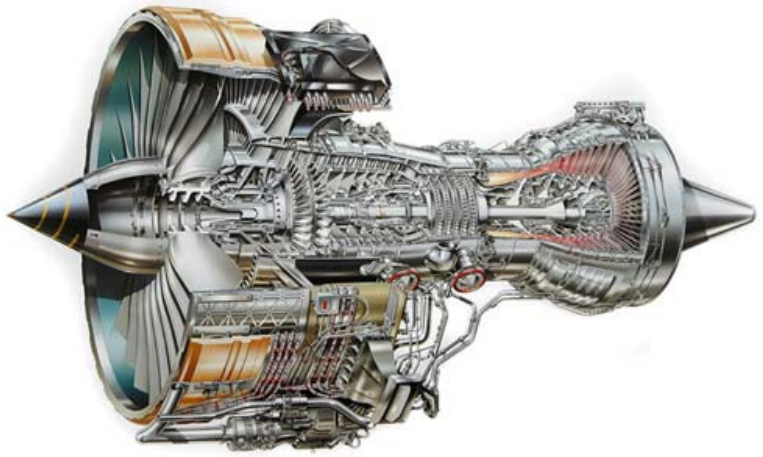
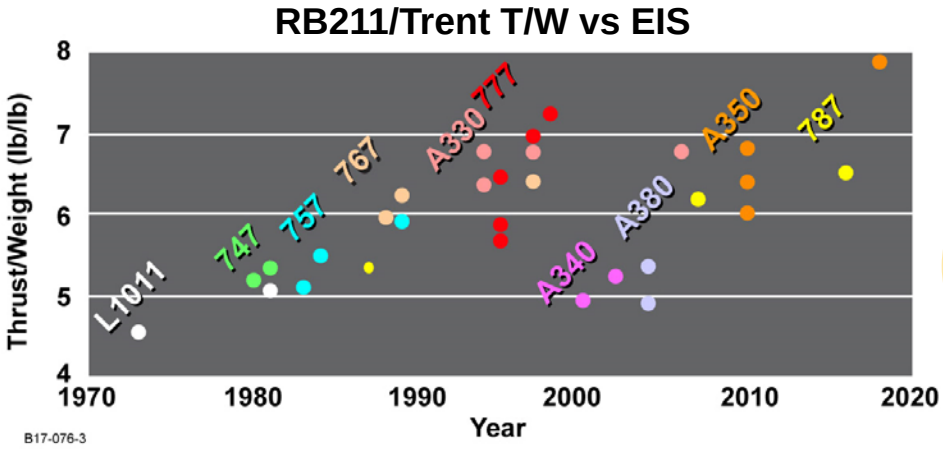
RR RB211 *(and Successor Trent Family) . . .*





- First fielded in 1972
- ~10,000+ units shipped
- Eleven apps, 43 models
- 37,000 to 104,000 lb F_n

. . . Enabled Modern Widebody Transport

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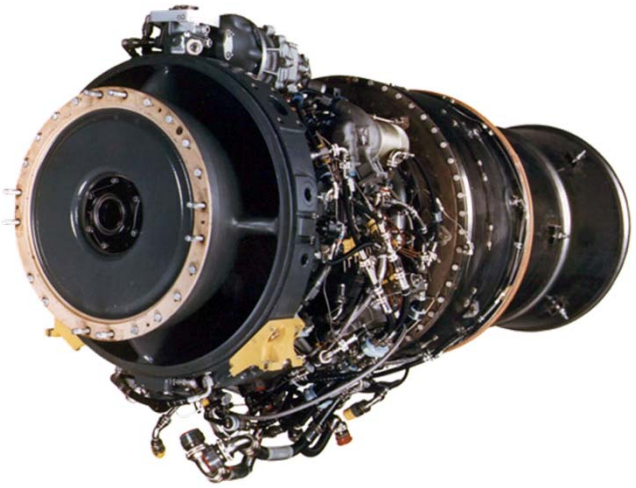
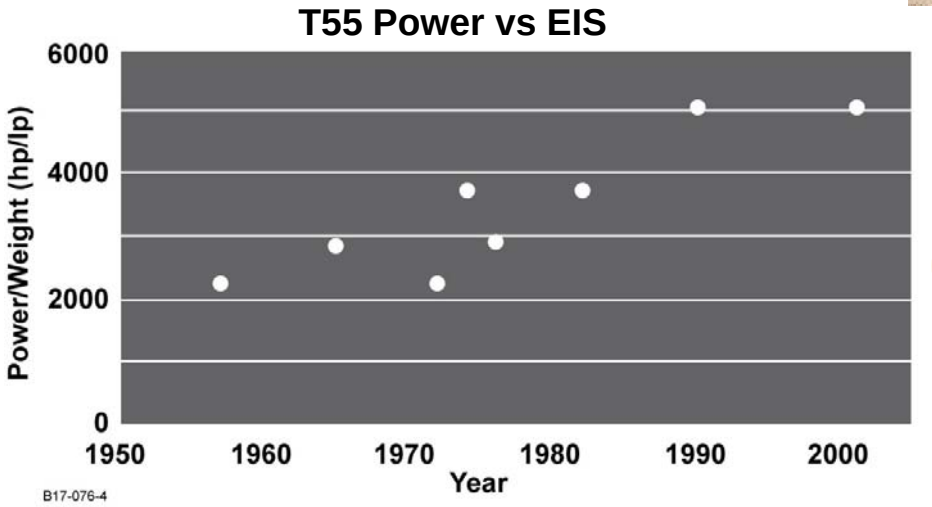
Avro Lycoming T55 . . .





- First fielded in 1957
- ~6200 units shipped
- Two applications, 10 models
- 2200 to 5000 shp

Spawned Turbofan and Marine variants

. . . Brought Helicopters Into the Turbine Engine Era

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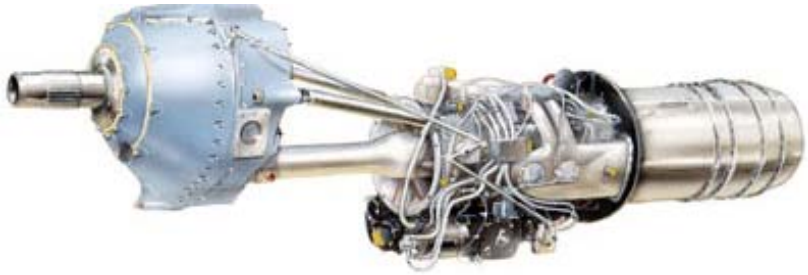
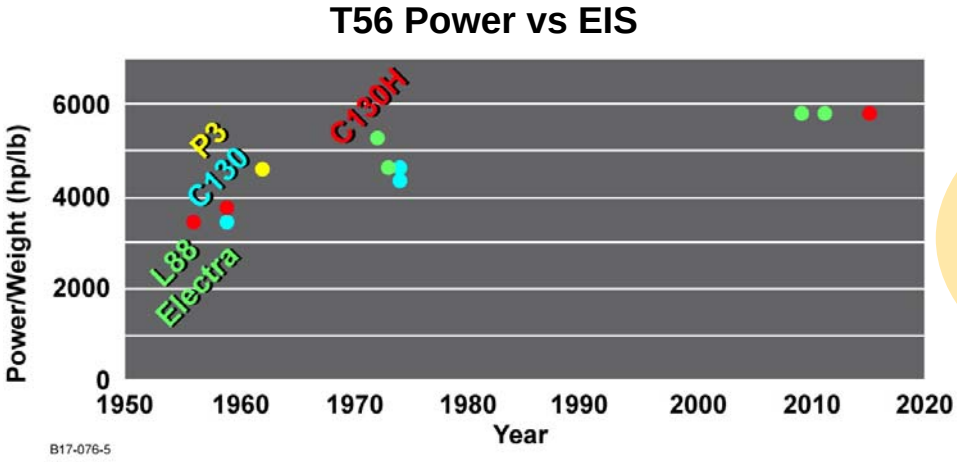
Allison T56 . . .





- First fielded in 1956
- ~18,000 units shipped
- Five applications, 21 models
- 3400 to 5800 shp

Spawned Industrial & Marine Variants

. . . Enabled Versatile Airplanes Like the C130

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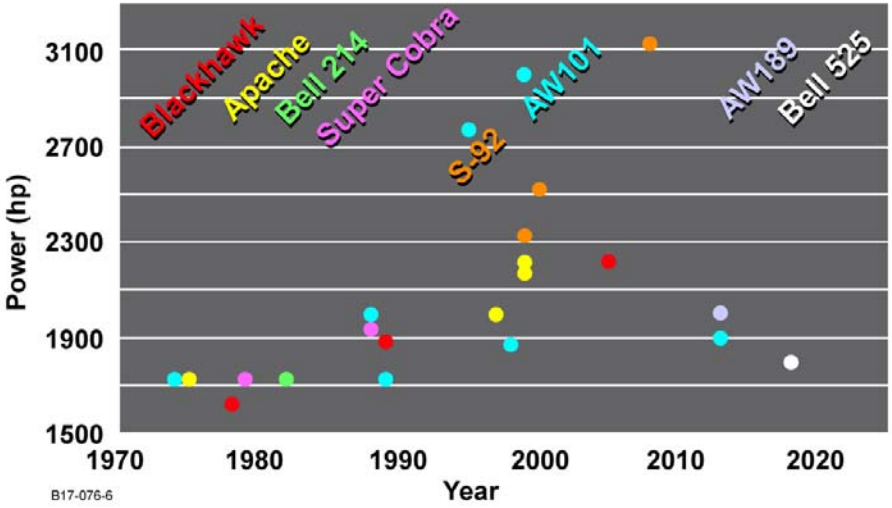
GE T700 . . .

T700 EIS vs Power



- First fielded in 1978
- ~20,000 units shipped
- 22 applications, 32 models
- 1300 to 3100 shp

Spawned Turboprop and Turbofan Variants

. . . Revolutionized Army Aviation

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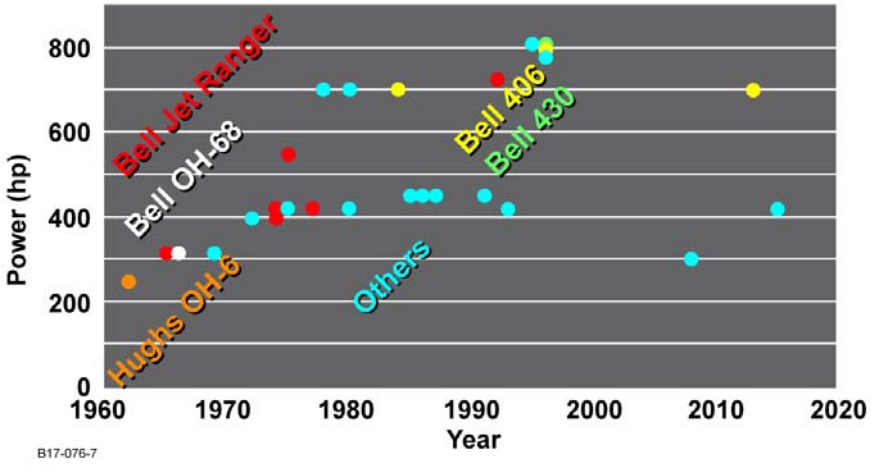
Allison T63 *(and Successor M250) . . .*

T63/M250 Power vs EIS



- First fielded in 1962
- ~31,000 units shipped
- 170 applications, 42 models
- 250 to 813 shp

Spawned Turboprop Variants

. . .Affordability Enabled New Class of Small Helicopters

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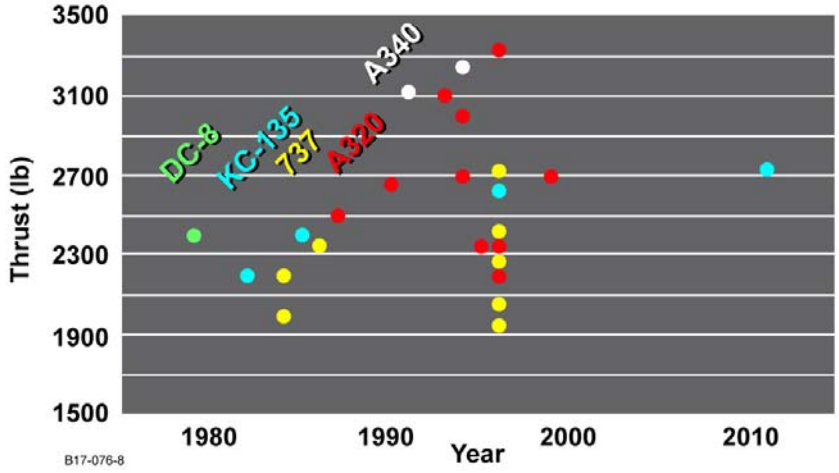
CFM International CFM56 . . .

CFM56 Thrust vs EIS



- First fielded in 1979
- ~30,000 units shipped
- Eight applications, 32 models
- 19,500 to 34,000 lb F_n

. . . Drove Affordable Narrowbody Transport

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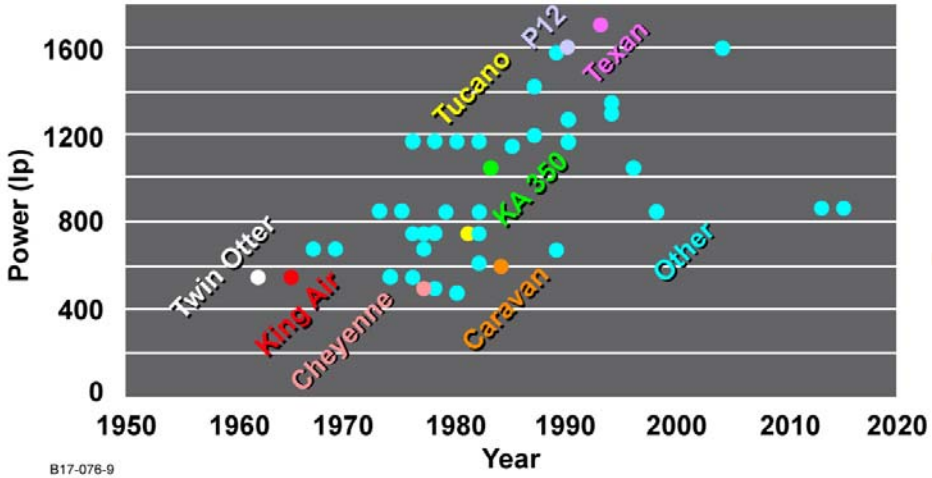
P&W PT6 . . .

PT6 Power vs EIS



- First fielded in 1979
- ~47,000 units shipped
- 100 applications
- 475 to 2300 shp

Spawned Helicopter Variants

. . . Created the General Aviation Turboprop Market

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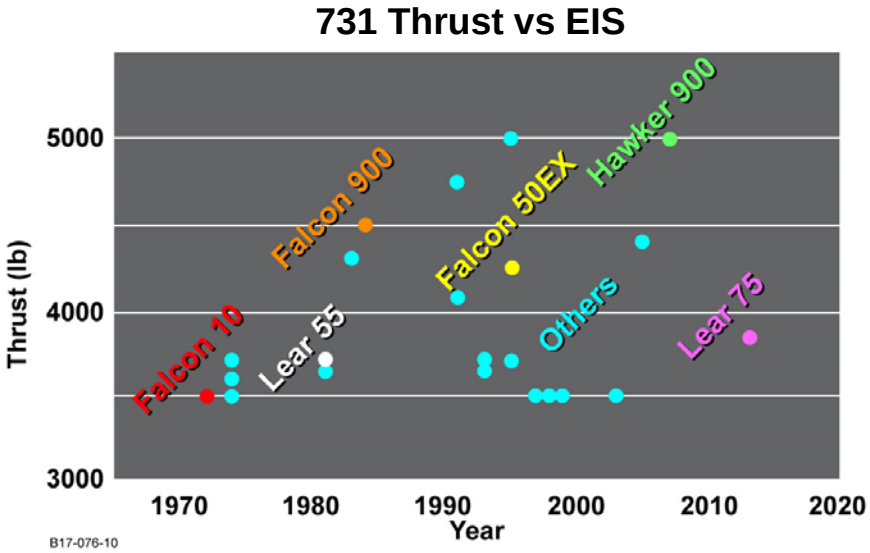
Garrett TFE731 . . .



- First fielded in 1972
- ~13,000 units shipped
- 76 applications
- 3500 to 5000 lb F_n

. . . Enabled Modern Business Jets

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Which Factors Influence ICONIC Propensity?

- Technology level at launch
- Architectural superiority
- First to market
- Smooth development
- Stable development funding source
- Clear application target at time of launch
- Core maturity at launch
- Other aircraft design features
- Operator reliability and serviceability
- Willingness to invest in on-going upgrades

. . .Or Prevent It?

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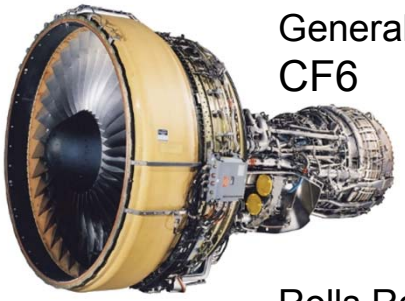
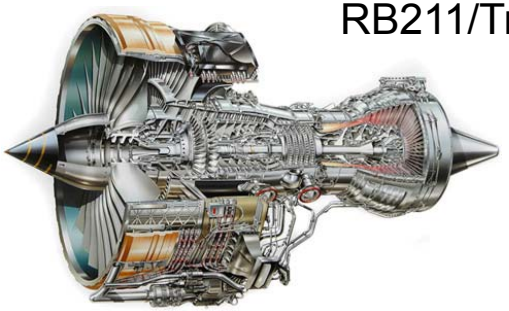
Widebody Engines: All Offered Competitive Technology

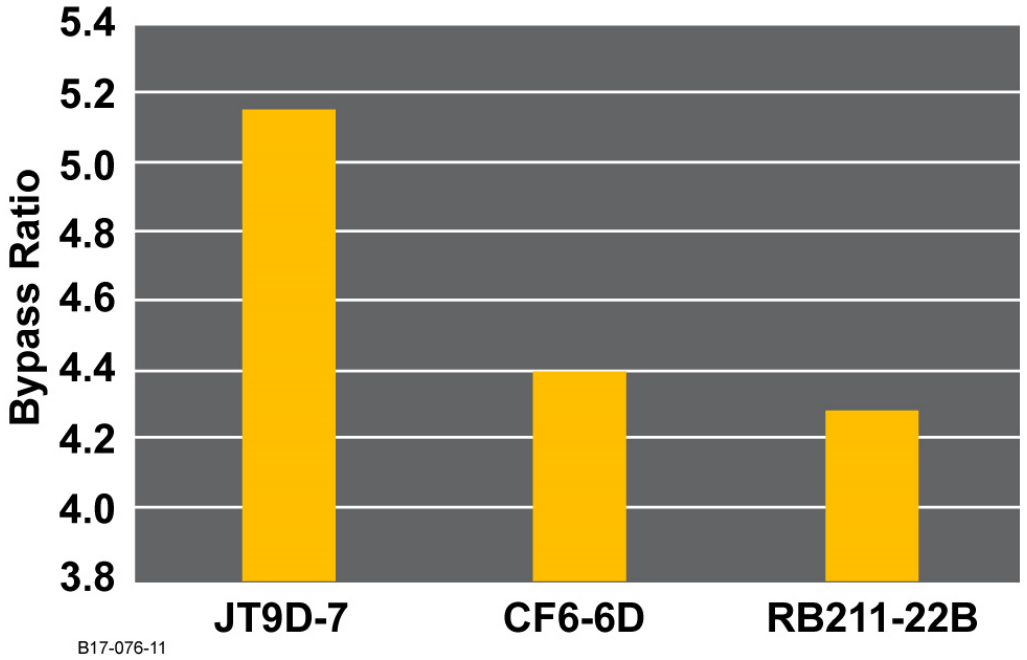
Pratt & Whitney
JT9/PW4000



General Electric
CF6



Rolls Royce
RB211/Trent



Every engine competitive at time of launch.
Balanced bypass ratio, weight, SFC to optimize their airplane

. . . ICONIC Status Unachievable Otherwise

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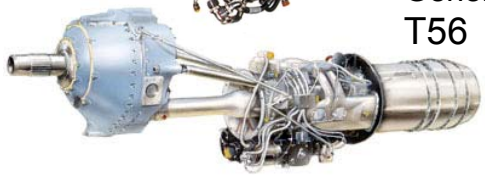
Military Engines: All Offered Superior Technology

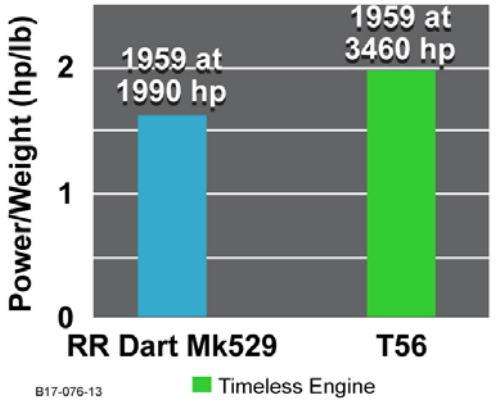
T55: no competitor at launch

Honeywell T55

General Electric T56

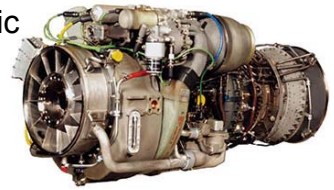


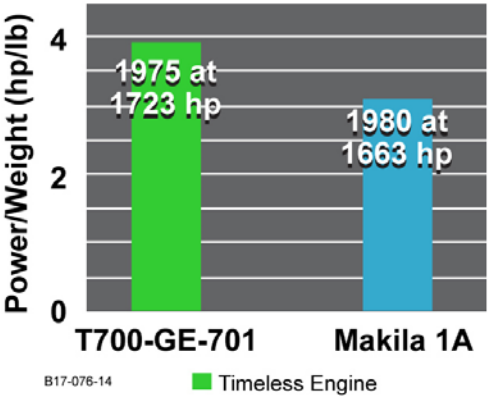
T56: superior at launch



T700: no competitor at launch

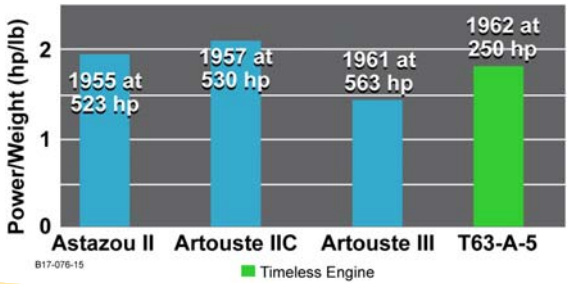
General Electric T700





Rolls Royce T63

T63: superior at launch



Typically, competition after launch is slim.
Engine must be superior to be selected

. . . Technology Level Critical in This Market

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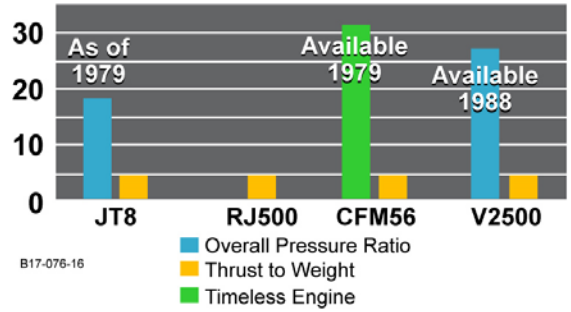
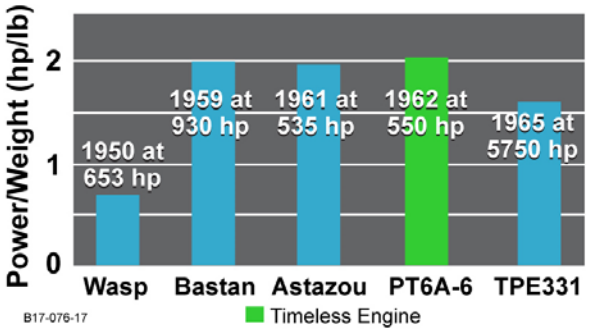
Small Commercial Engines . . .

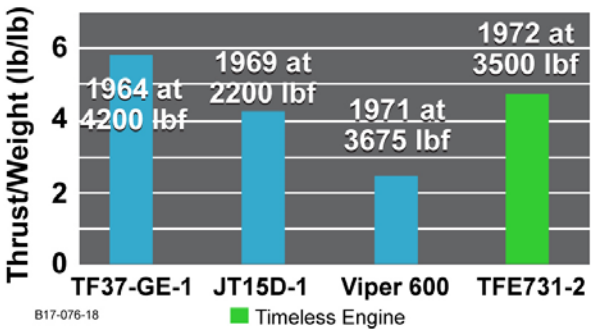
These engines, through technical superiority, enabled new markets



CFM
CFM56



Pratt & Whitney
PT6



Honeywell
TFE731

. . . All Were Technically Superior at Time of Launch!

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Architectural Innovation Helps Differentiate. . .

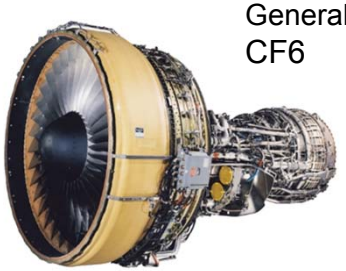
Pratt & Whitney
JT9/PW4000

Honeywell
T55

General Electric
T56

T56
Very Small All-Axial Compressor

CFM
CFM56



General Electric
CF6

General Electric
T700

T700
Very High OPR

PT6
Installation and Service Focus in Design

Pratt & Whitney
PT6

Rolls Royce
RB211/Trent

RB211
First Three Spool

Rolls Royce
T63

T63
Design Focus on Affordability

TFE731
First Geared Fan

Honeywell
TFE731

60% launched with differentiating architecture

. . . But is Not Necessarily Required

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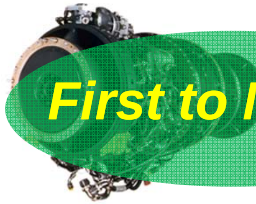
First to Market Can't Hurt . . .

Pratt & Whitney
JT9/PW4000

First to Market



Honeywell
T55

First to Market

CFM
CFM56

General Electric
T56

General Electric
CF6

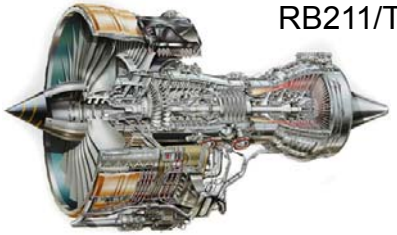
First for DC10 vs L-1011,
But not first for B747

General Electric
T700

First to Market

First to Market

Pratt & Whitney
PT6



Rolls Royce
RB211/Trent

Rolls Royce
T63

First to Market

Honeywell
TFE731

60% were
First to Market

. . . But Won't Always Ensure ICONIC Status

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Development Struggles . . .

Pratt & Whitney

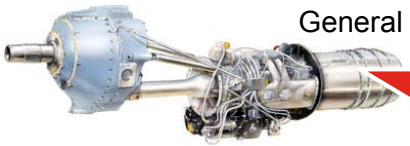
JT9/ PW4000

Lycoming

T55

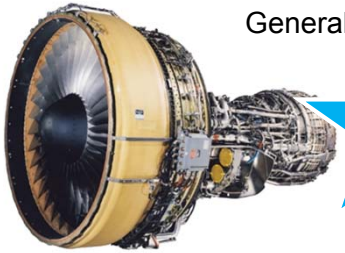
CFM

CFM56



General Electric

T56



General Electric

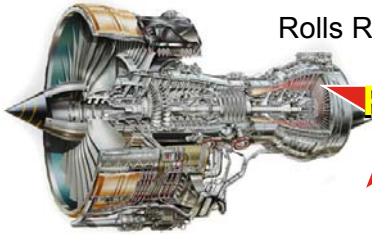
CF6

General Electric

T700

Pratt & Whitney

PT6



Rolls Royce

RB211/ Trent

Rolls Royce

T63

Honeywell

TFE731

Many ICONIC models struggled through development!!

Known to be smooth

Limited public record

Known issues

Documented serious issues

. . . Do NOT Preclude ICONIC Status

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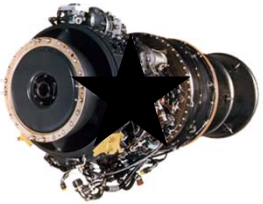
Government Funding for Development Helps . . .

Pratt & Whitney

JT9/ PW4000

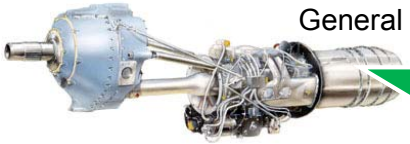


Lycoming

T55

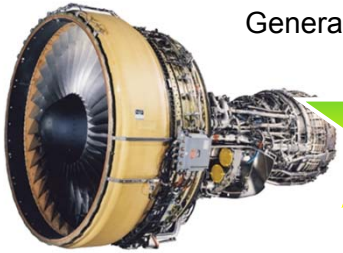
CFM

CFM56



General Electric

T56



General Electric

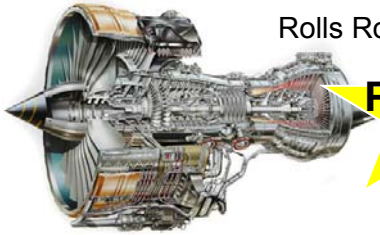
CF6

General Electric

T700

Pratt & Whitney

PT6



Rolls Royce

RB211/ Trent

Rolls Royce

T63

Honeywell

TFE731

60% were “government funded”;
later leveraged for commercial use.
Competitiveness at initial selection critical!

Government funded

Underlying core developed with Government funding

Commercially funded

. . . But, the Engine Has to be Superior to Win!

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Mature Core Technology . . .

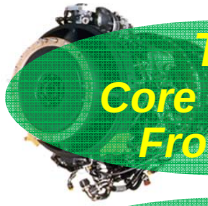
Pratt & Whitney
JT9/PW4000

General Electric
CF6

CF6 Core Lineage From TF39

Rolls Royce
RB211/Trent

RB211 Core Lineage From RB203 (1967)



Honeywell
T55

T55 Core Lineage From T53

T56 Core Lineage from T38

General Electric
T56

General Electric
T700

Rolls Royce
T63

CFM56 Core Lineage From F101

CFM
CFM56

Pratt & Whitney
PT6

TFE731 Core Lineage From DC10 APU

Honeywell
TFE731

60% launched using core adapted from legacy engine

. . . Benefits the Quest for "ICONIC" Status

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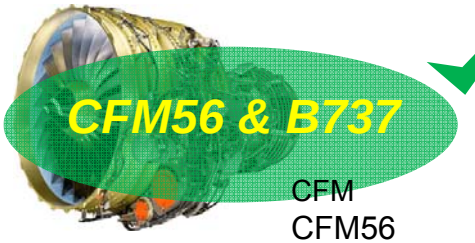
Aircraft and Engine Can Be Synergistic . . .

JT9 & B747

Pratt & Whitney
JT9/PW4000

T55 & Chinook

Honeywell
T55



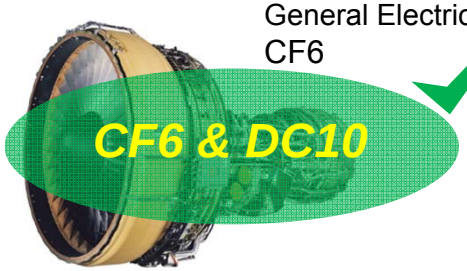
CFM56 & B737

CFM
CFM56

T56 & C130

General Electric
T56

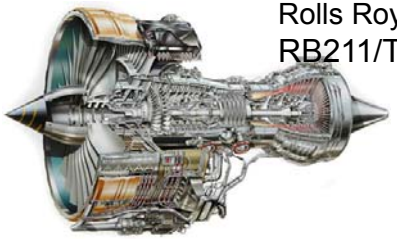
General Electric
CF6



CF6 & DC10

General Electric
T700

Pratt & Whitney
PT6



Rolls Royce
RB211/Trent

Rolls Royce
T63

Honeywell
TFE731

The engine success helps the aircraft;
The aircraft success helps the engine

. . . In the Pursuit of ICONIC Status

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Specific Application Target at Launch Helps . . .

JT9 – B747

Pratt & Whitney
JT9/PW4000

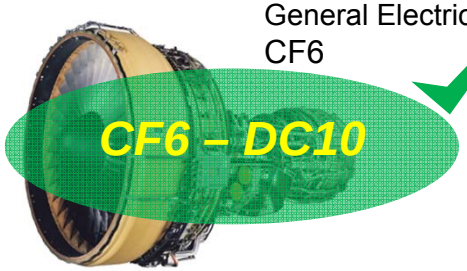
Honeywell
T55

General Electric
T56

T56 – C130

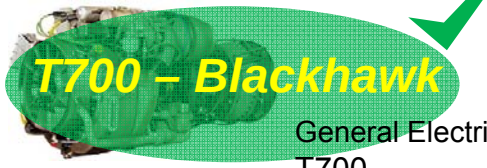
CFM
CFM56

General Electric
CF6



CF6 – DC10

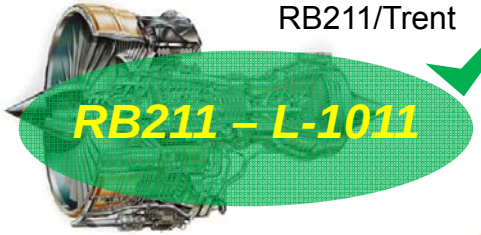
Pratt & Whitney
PT6



T700 – Blackhawk

General Electric
T700

Rolls Royce
RB211/Trent



RB211 – L-1011

Rolls Royce
T63

Honeywell
TFE731

- 50% had specific launch platform
- Engine must align with market expectations.
- But, a great first platform really helps!

. . . But Is Not Required for ICONIC Status

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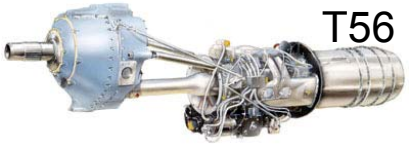
Operational Reliability Must be Achieved. . .

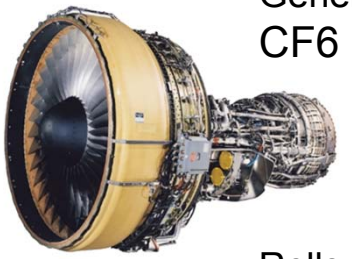
Pratt & Whitney
JT9/PW4000

Honeywell
T55

CFM
CFM56

General Electric
T56



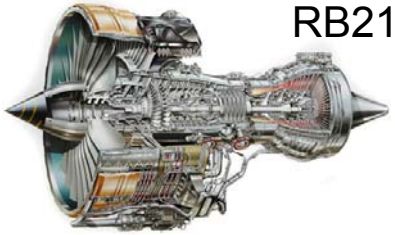


General Electric
CF6

General Electric
T700

Pratt & Whitney
PT6

Rolls Royce
RB211/Trent



Rolls Royce
T63

Honeywell
TFE731

- In service issues for these engines were addressed.
  - Some engines missing because issues were not addressed!
- Operators hold these engines in high esteem.

. . . To Earn Iconic Status

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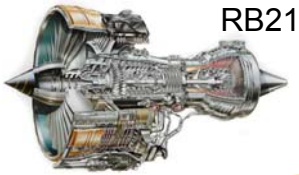
Be Willing to Invest in Upgrades . . .

Pratt & Whitney
JT9/PW4000

General Electric
CF6



Rolls Royce
RB211/Trent

Honeywell
T55

General Electric
T56

General Electric
T700

Rolls Royce
T63

CFM
CFM56

Pratt & Whitney
PT6

Honeywell
TFE731

- 100% demonstrate intentional pattern of technology infusion
  - Investing in upgrades and enhancements
  - Infusion of technology
- Some engines are missing because they didn't infuse tech!
  - Example: Would F110 exist if F100 launched tech infusion?

. . . To Maintain Market Share and Earn Iconic Status

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As a Turbine Engine Practitioner . . .

What can I do
to Secure my Product's
"ICONIC" Legacy?

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When Conceiving a Product Launch . . .

- Understand the needs and preferences in your market space
- Take account of adjacent trends and competitors
- A technically inferior product won't make it
- Make sure it will work
  - New technology NEEDS to be successfully vetted!
  - Novel architecture should be highly scrutinized to ensure success
  - Pulling from proven core helps provide confidence!
- Be sensitive to the financials in your market
  - Needs to be affordable!
  - Installation and aircraft interfaces need to be flawless!
- First to market helps
  - Government-funded projects give one chance (be the best)

. . . Do Some Heavy Lifting in Advance

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After Initial LAUNCH Application . . .

- Resolving reliability and serviceability issues is crucial
- Focus on keeping technologically current
  - Infusion of technology is absolutely necessary
    - For safety and evolving regulations
    - For power density and fuel burn
    - For emissions and noise
    - For cost-of-ownership
- You must make engine changes to help your customer's aircraft platform stay competitive!
- Adapt to changing environments
  - Look beyond the turbomachine for expectations (poll customers)
  - Example: connectivity is the new normal

Refusal to Evolve Can Severely Limit Your Chances for Success!

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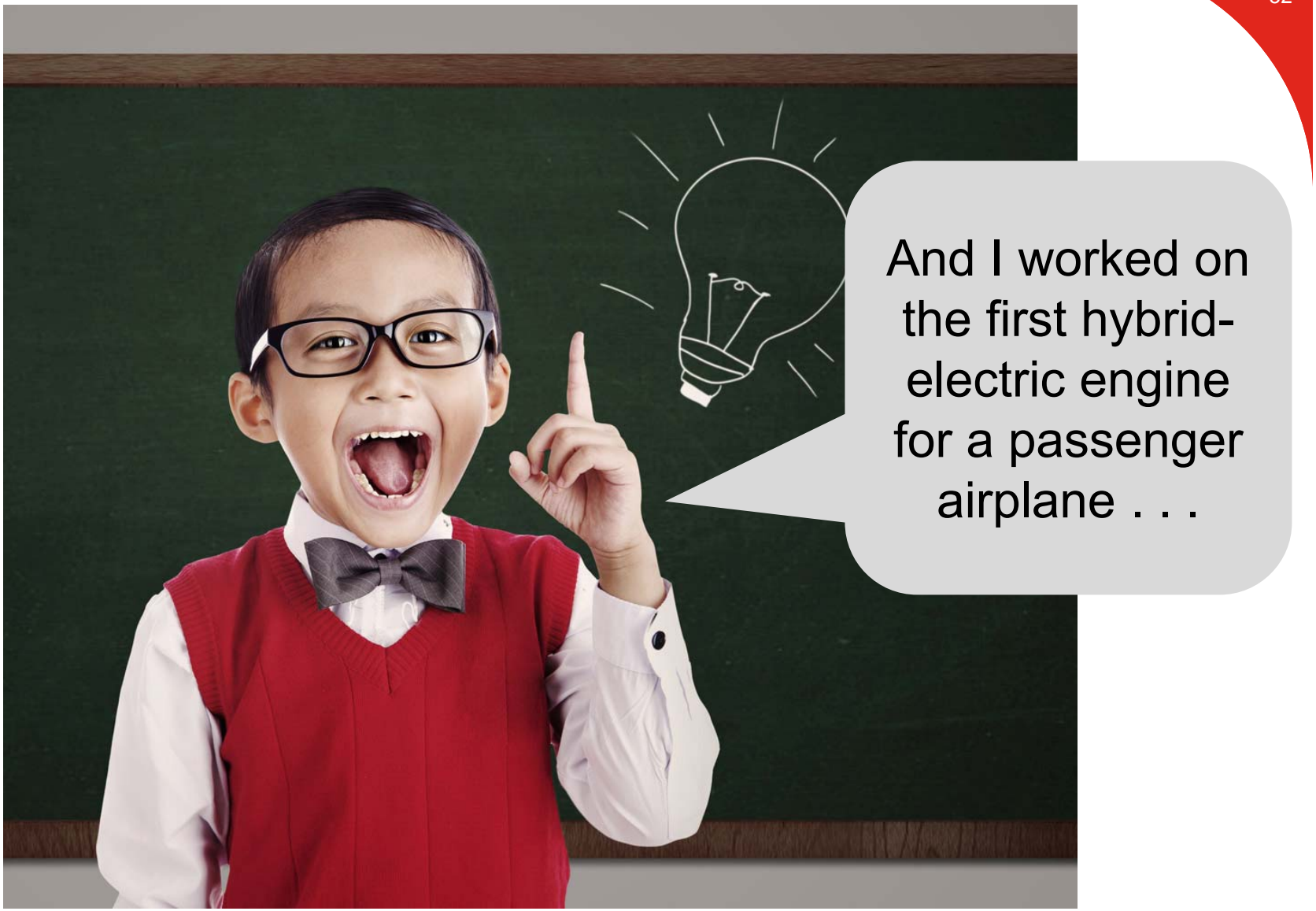

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