Aviation Energy Management
… *A System's Approach*

Green Aviation Workshop

GE Aviation

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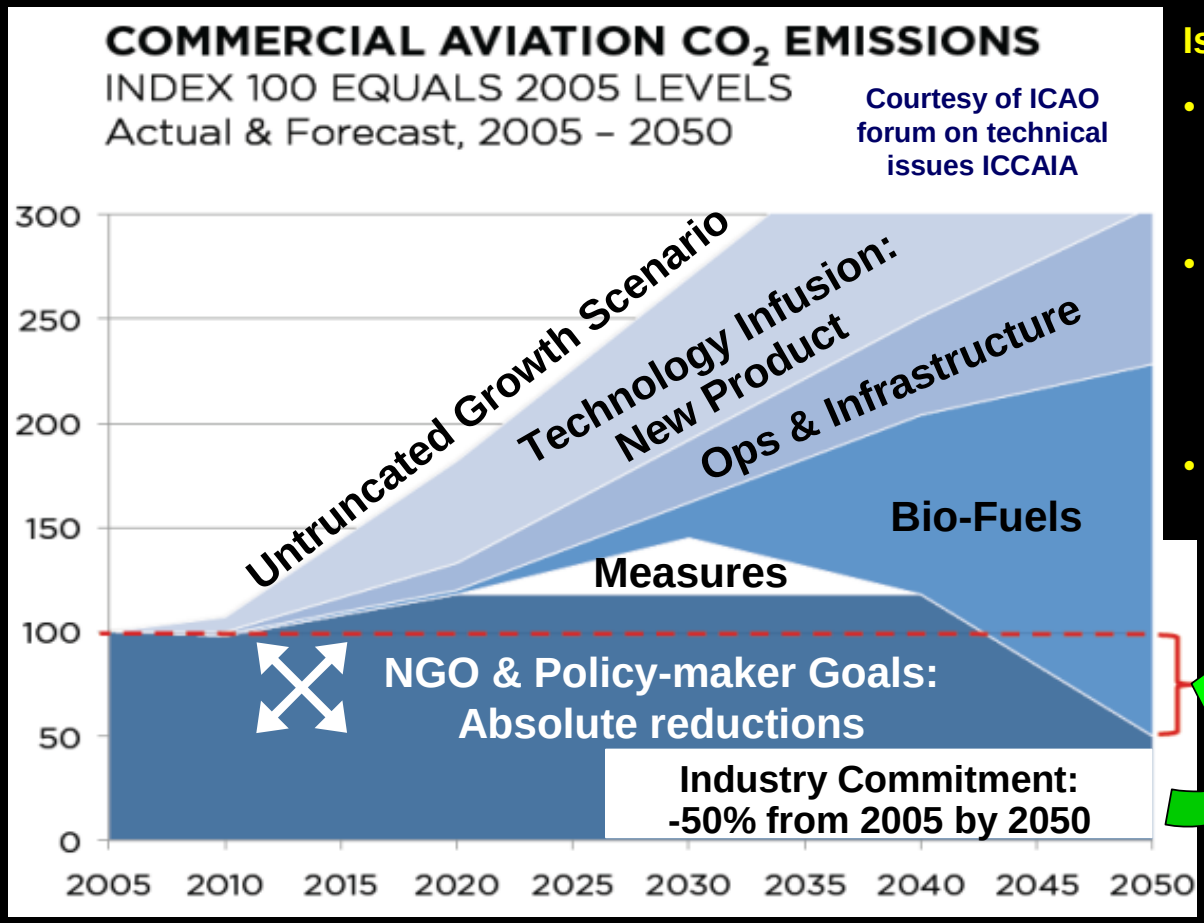
9 September 2010

Imagination at work

It's more than energy alone...



Issues:

- **Bio-Fuels: How quickly do they come on board?**
- **Technology Infusion: Who pays for legacy retirements or upgrades?**
- **Targets: Only through limiting growth?**

Future Generational Challenges

The Threats … Current And Emerging

CORNERS OF THE TRADE SPACE	N+1 GENERATION (2015)* Conventional Configurations relative to 1998 reference	N+2 GENERATION (2020)* Unconventional Configurations relative to 1998 reference	N+3 GENERATION (2025)* Advanced Aircraft Concepts relative to user-defined reference
Noise (below Stage 4)	**-32 dB**	**-42 dB**	**-71 dB**
LTO NOx Emissions (below CAEP 6)	**-60%**	**-75%**	**Better than -75%**
Performance: **Fuel Burn**	**-33%****	**-40%****	**Better than -70%**
Performance: **Field Length**	**-33%**	**-50%**	**Exploit metro-plex concepts*****

*Technology Readiness Level for key technologies = 4-6
** Additional gains may be possible through operational improvements
*** Concepts enabling optimal use of runways at multiple airports within a metropolitan area

… But Not Enough To Meet Our Customer's Goals!

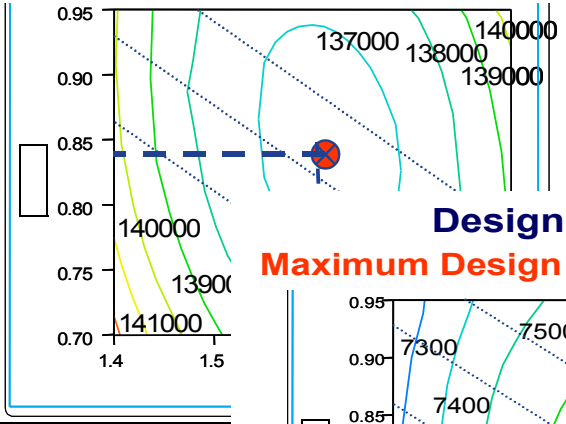
Must Consider "Break-With" technologies to meet future needs

Tradable Goals Needed for Balanced Solution

Engine Study Example: Fan Pressure Ratio

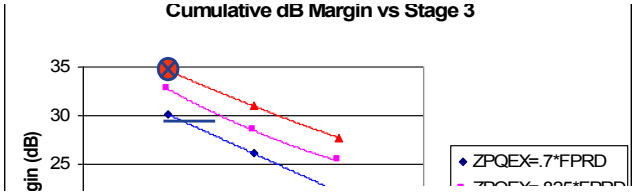
Fuel Burn

Minimum Fuel Burn @ 1.62 FPR



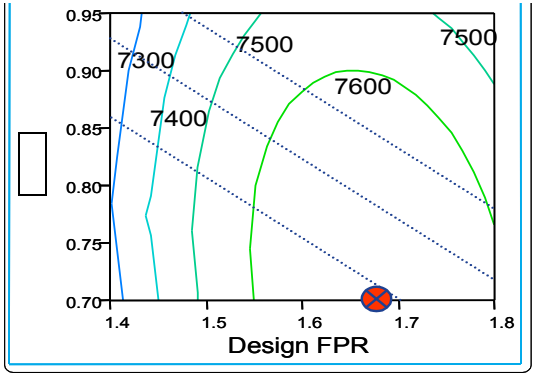
Acoustic Margin

Minimum Noise @ 1.40 FPR



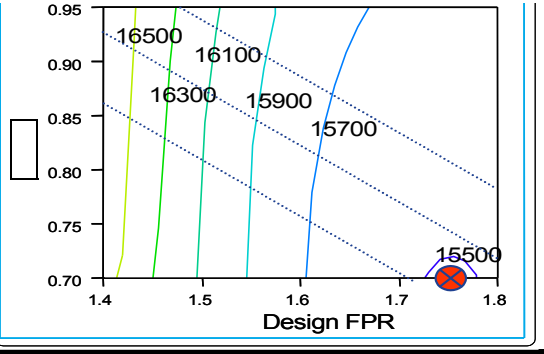
Design Range

Maximum Design Range @ 1.67 FPR



EROC
(Engine Related Operating Cost)

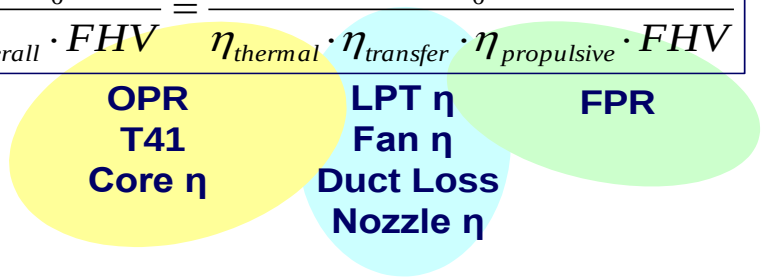
Minimum EROC @ 1.77 FPR



Revolutionary Systems That Break With Evolutionary Thinking

- Develop Revolutionary technologies to address key goals for balanced system solution
  - Long term goals with near term technology off ramps
- Focus on key variables that influence propulsion system efficiency

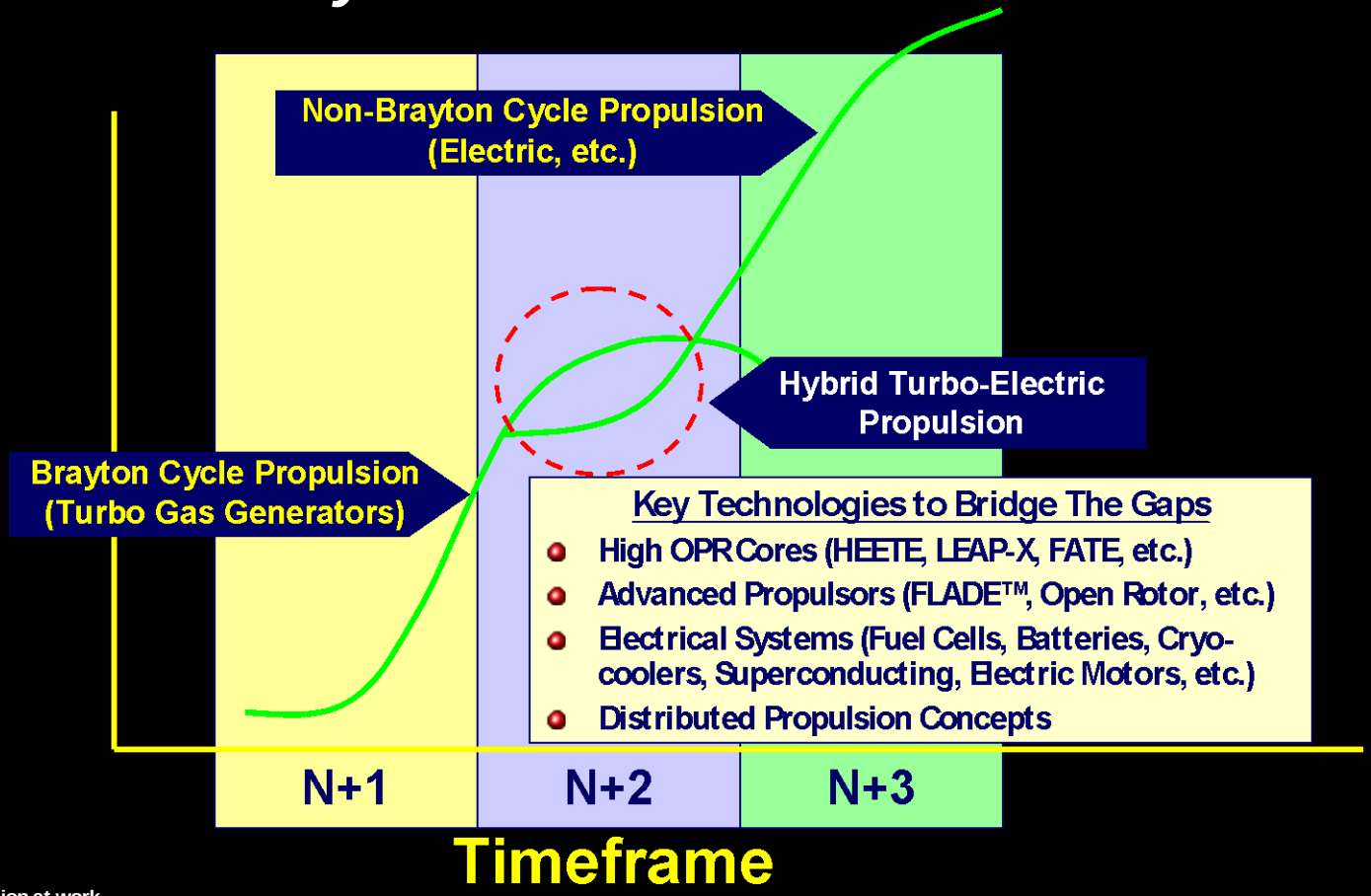
$$SFC = \frac{w_f}{F_n} \approx \frac{v_0}{\eta_{overall} \cdot FHV} = \frac{v_0}{\eta_{thermal} \cdot \eta_{transfer} \cdot \eta_{propulsive} \cdot FHV}$$



- Systems approach Needed
  - Need to work technology TRL and MRL together
    - Technologies must be easily manufactured and affordable
  - Can't ignore broader system opportunities … what about the mission?

Vision for 2030 – 2050 Propulsion

Revolutionary Ideas For Future Aviation



Imagination at work

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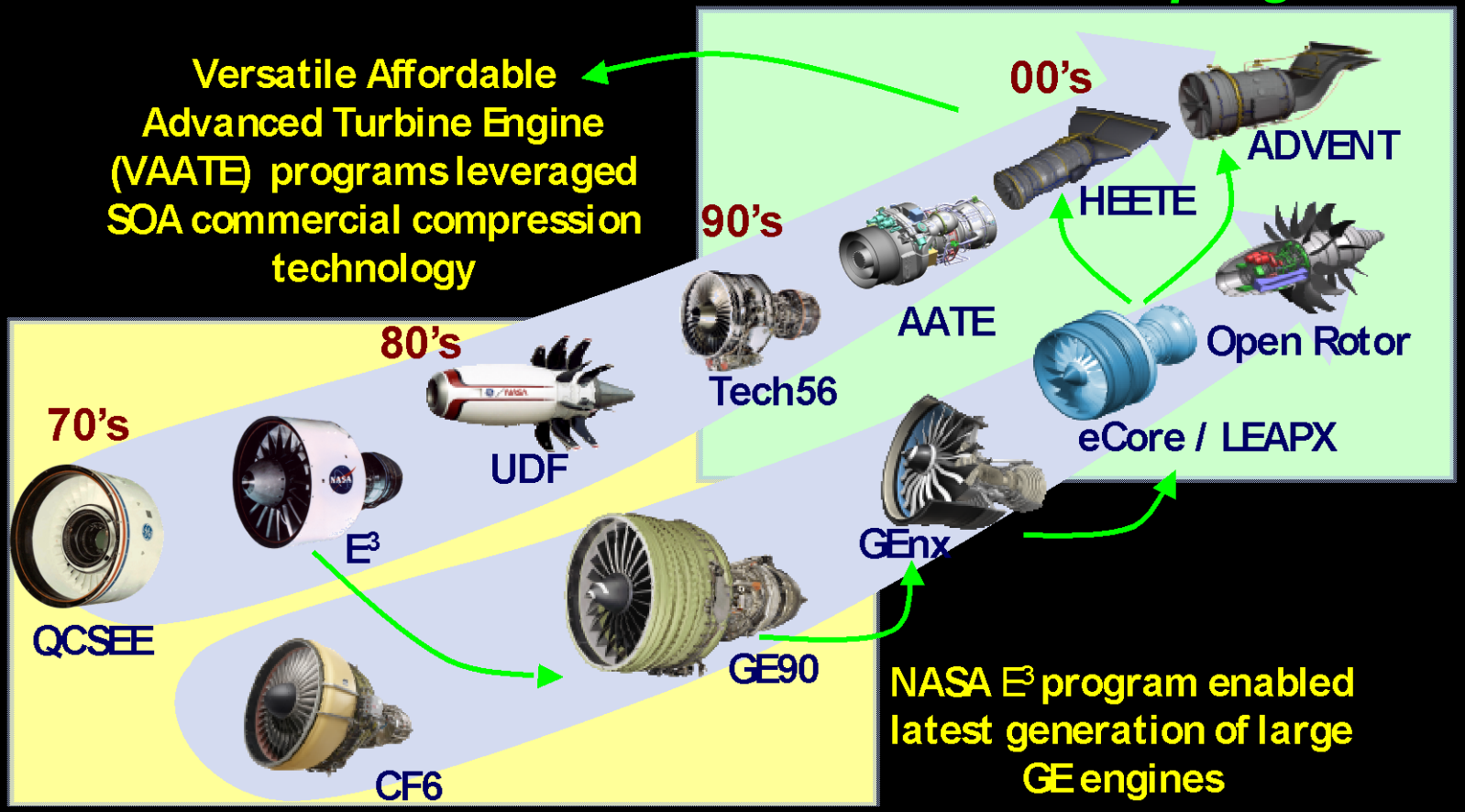
Key Pacing Items for Future Programs

Increased Integration Needed Sooner in Process

N+1	N+2	N+3
Refining Propulsion		
Non-Metallic Materials	LEAP-X Program (~2016)	
Distributed Controls		
Advancing Propulsion		
Advanced Metallics & Coatings		TiAl on GEnx ™, Icephobic
Advanced Architectures		Open Rotor, ADVENT
Full Thermal / Power Mgmt and Optimization		INVENT
Flight Path Optimization		4D Trajectory
Revolutionary Propulsion		
Non-Brayton Cycles		CVC, DARPA Vulcan
Hybrid-Electric Propulsion		Fuel Cells, Batteries
Distributed Propulsion		Embedded, Pylon Mounted, Electric

R&D funding:

Give & take between USG and commercial programs



NASA E^3 program enabled latest generation of large GE engines

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Revolutionary Approaches Needed for the Future

- Revolutionary Architectures
  - High efficiency, non-Brayton cycle
  - High power density fuel cells / batteries
- Materials
  - Lighter weight, higher temperatures
- Highly Integrated Systems
  - Systems designed in parallel … optimizing sub-system capabilities
- Government Sponsored Test Programs
  - Drive success toward common goals