OVERVIEW OF ULTRA-EFFICIENT ENGINE TECHNOLOGY (UEET) PROGRAM

Joe Shaw
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

UEET

Overview of

Ultra-Efficient Engine Technology (UEET) Program

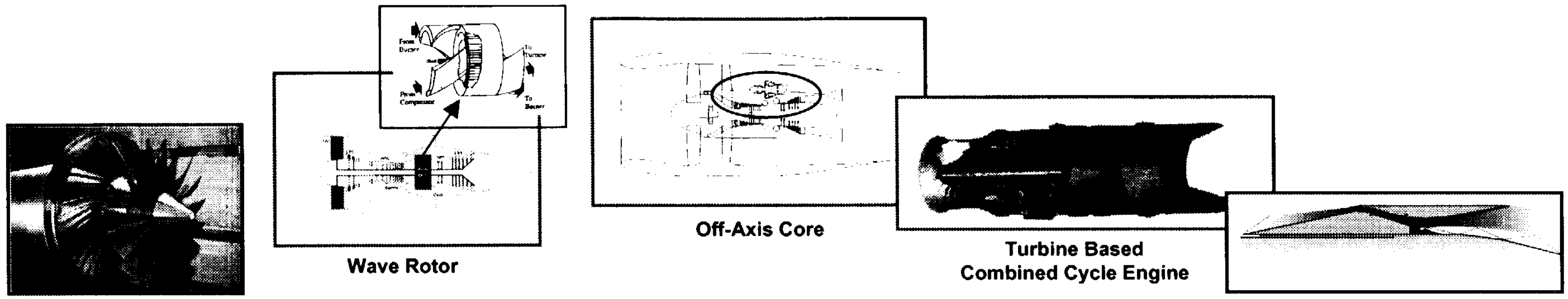
Joe Shaw
Chief, UEET Program Office
NASA Glenn Research Center
Cleveland, OH 44135

UEET *Administrator's Charge to NASA Glenn*

Administrator's November 20, 1998 charge to NASA Glenn.....

Plan a 5 yr. engine technology program that will enable next generation engines for both commercial and military applications. Emphasize revolutionary technologies that will enable future subsonic and high-speed applications. Actively seek collaboration with the DOD.

UEET Vision Statement (Draft)



Advanced Subsonic Turbofan

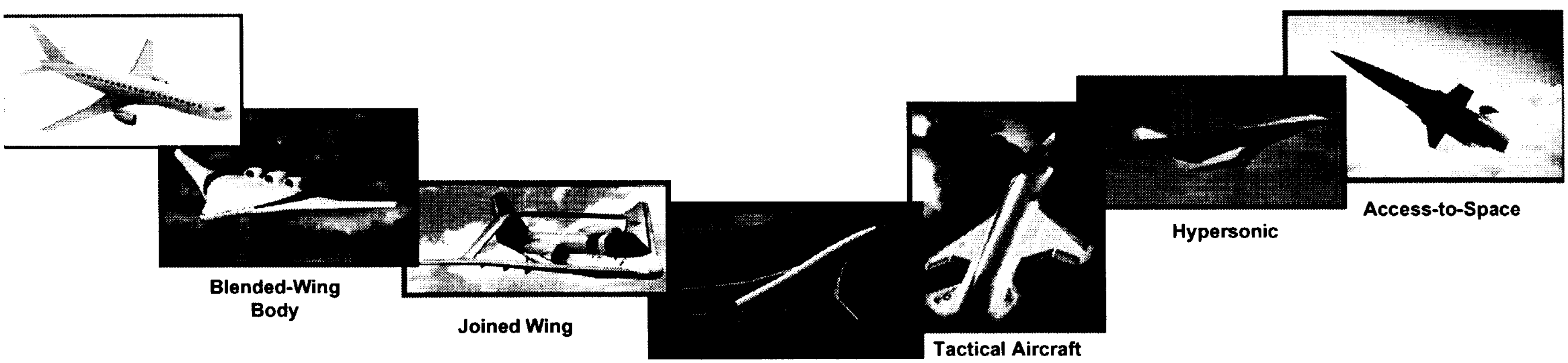
Wave Rotor

Off-Axis Core

Turbine Based Combined Cycle Engine

Rocket-Based Combined Cycle

Develop and transfer revolutionary propulsion technologies that will enable future generation vehicles over a wide range of flight speeds.



Blended-Wing Body

Joined Wing

Supersonic Transport

Tactical Aircraft

Hypersonic

Access-to-Space

September 28, 1999
mn_UEETASTAC/PSS

3

Program Goals

Develop and transfer revolutionary propulsion technologies that will enable future generation vehicles over a wide range of flight speeds.

- **Address long term aviation growth potential without impact on climate by providing technology for dramatic increases in efficiency to enable reductions in CO_2 based on an overall fuel savings goal of up to 15%.**
- **Address local air quality concerns as well as addressing potential ozone depletion by developing technology for 70% NOx emissions reduction at take-off and landing conditions, and also technology to enable aircraft to not impact the ozone layer during cruise operation.**
- **Technology Readiness to the <u>Component Level</u> (TRL 4-5).**

Investment Areas

Ultra-Efficient Engine Technology

Combustion
- Ultra-Low NOX Combustors
- Particulates/ Aerosols & other Emittents

Turbomachinery
- Fans
- Highly Loaded Compressors
- Highly Loaded/ Coupled HP/LP Turbines

Materials & Structures
- CMC Liner & Vane
- Adv. Materials
  - Disk
  - Airfoils
- Light Weight Nozzle Structure
- High Temperature PMC

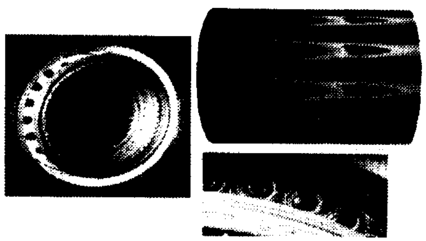
Propulsion/ Airframe Integration
- Smart Nacelle technology
- Advanced PAI Methodologies Development
- Conventional/unconventional installations

System Integration & Assessment
- System Analysis and Benefit Assessment
- Technology Requirements
- Simulations to Reduce Testing
- Assessment including Environmental Impact

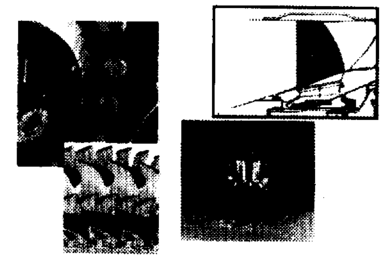
A Portfolio of Enabling Technologies for Future Generations of High Performance Engines (Commercial and Military)

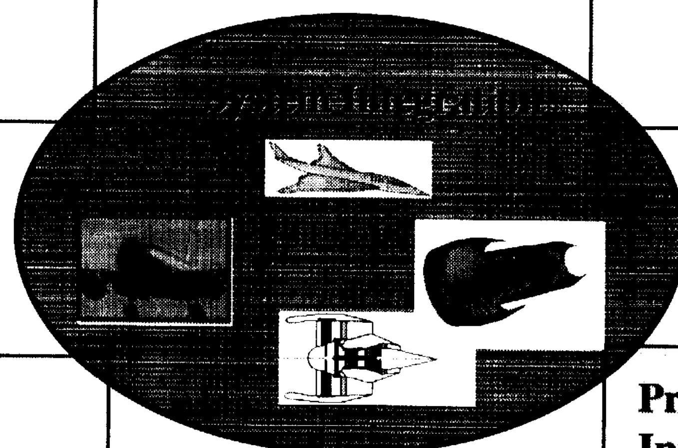
UEET Investment Areas for Baseline Program

Combustion

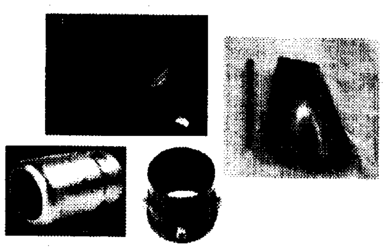


Turbomachinery

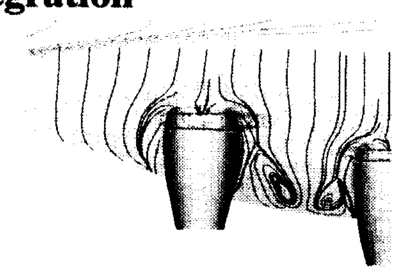




Materials and Structures



Propulsion/Airframe Integration



September 28, 1999
mn_UEETASTAC/PSS

UEET

NASA's Technology Readiness Level (TRL) Scale Applied to UEET Program

Industry Role ↔ Government Role

- System Test and Operations (TRL 8–9)
- System/Subsystem Development (TRL 6–8)
- Technology Demonstration (TRL 5–6)
- Technology Development (TRL 3–5)
- Research to Prove Feasibility (TRL 2–3)
- Basic Technology Research (TRL 1–2)

TRL	General NASA Definition
9	Actual system "flight proven" on operational flight
8	Actual system completed and "flight qualified" through test and demonstration
7	System prototype demonstrated in flight environment
6	System/subsystem model or prototype demonstrated/validated in a relevant environment
5	Component and/or breadboard verification in a relevant environment
4	Component and/or breadboard test in a laboratory environment
3	Analytical and experimental critical function, or characteristic proof-of-concept
2	Technology concept and/or application formulated (candidate selected)
1	Basic principles observed and reported

UEET Program (TRL 3–5)

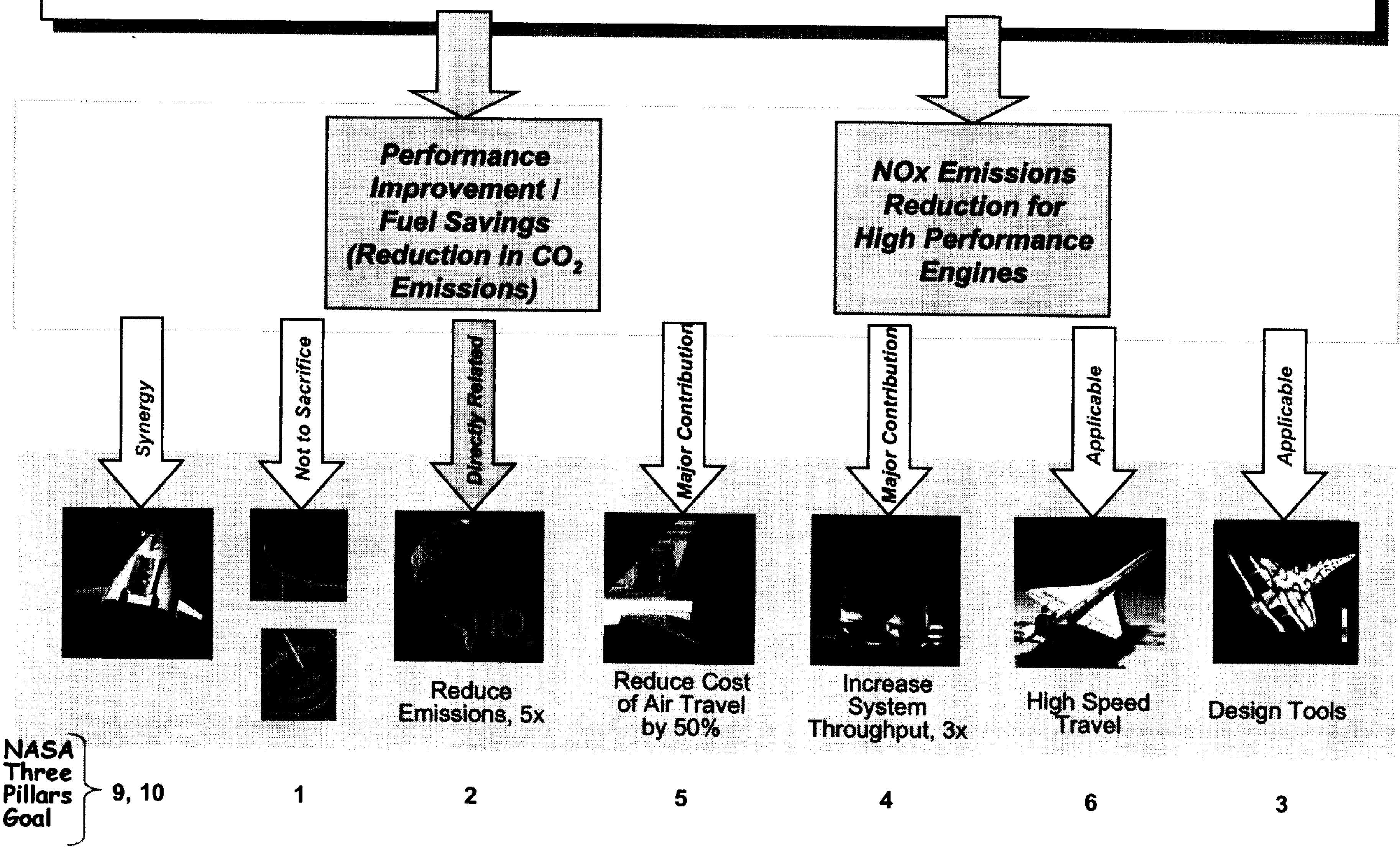
HSR and AST Planned Span (TRL 2–6)

September 28, 1999
mn_UEETASTAC/PSS

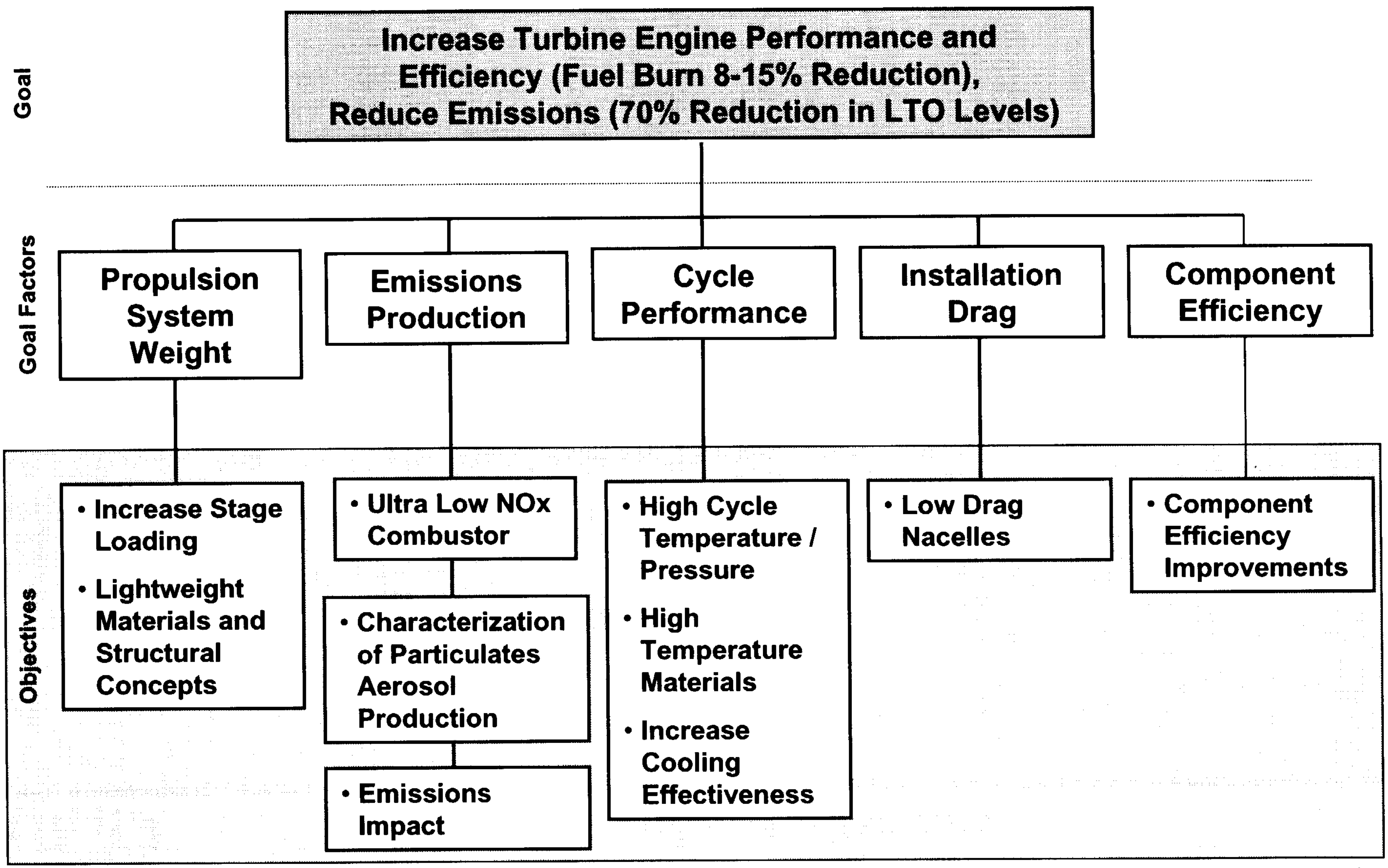
7

Ultra-Efficient Engine Technology Program

Increased engine performance to enable and enhance a wide range of revolutionary aircraft from small to large, and over a wide range of flight speeds



UEET Overview



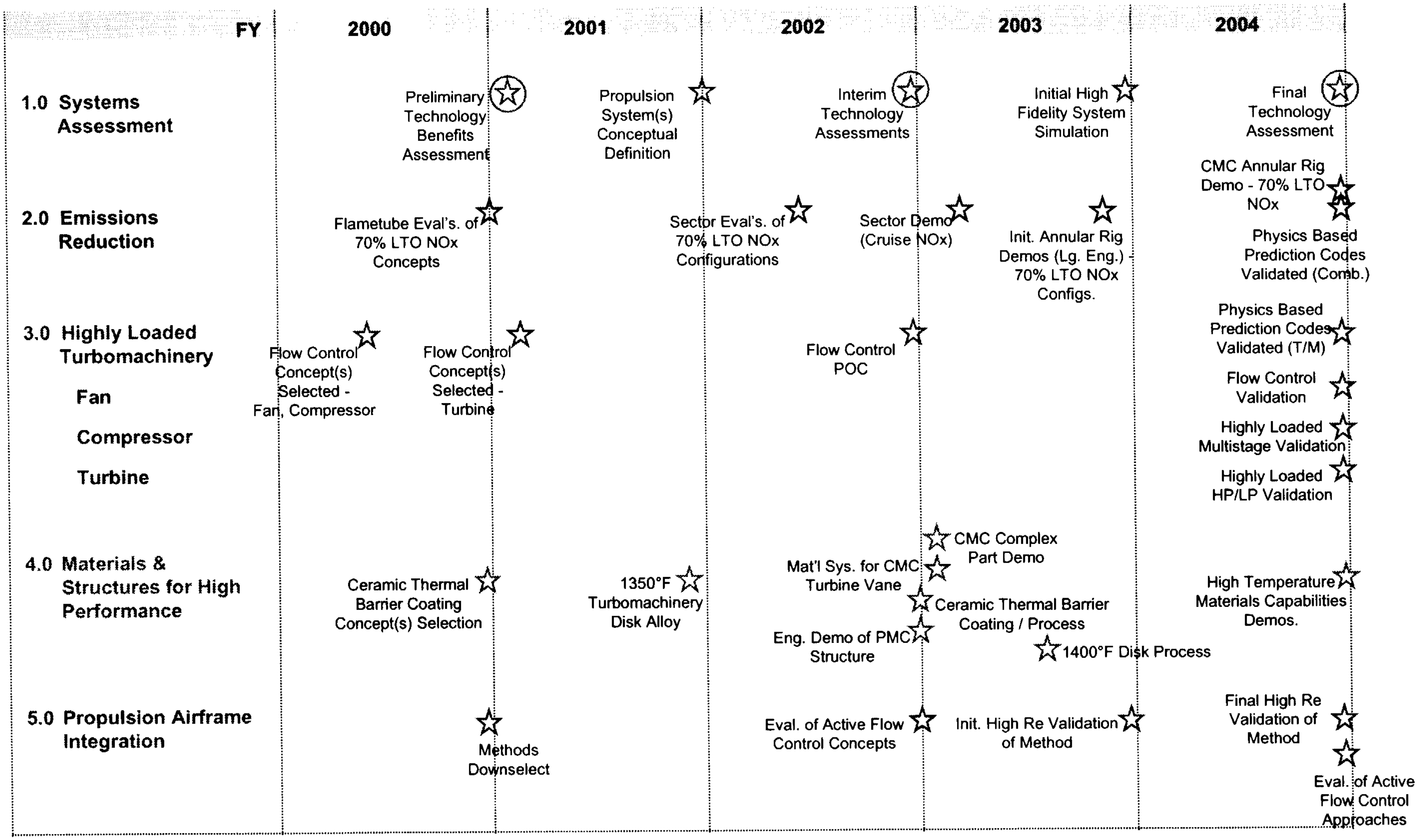
September 28, 1999
mn_UEETASTAC/PSS

UEET — Work Breakdown Structure

1.0	Systems Assessment
2.0	Emissions Reduction
3.0	Highly Loaded Turbomachinery
4.0	Materials and Structures for High Performance
5.0	Propulsion Airframe Integration
6.0	Program Management

UEET

Level I Milestone Schedule



Notes: 1) All level I milestones are GPRA.
2) PCA milestones are denoted by ⊛

September 28, 1999
mn_UEETASTAC/PSS

11

UEET

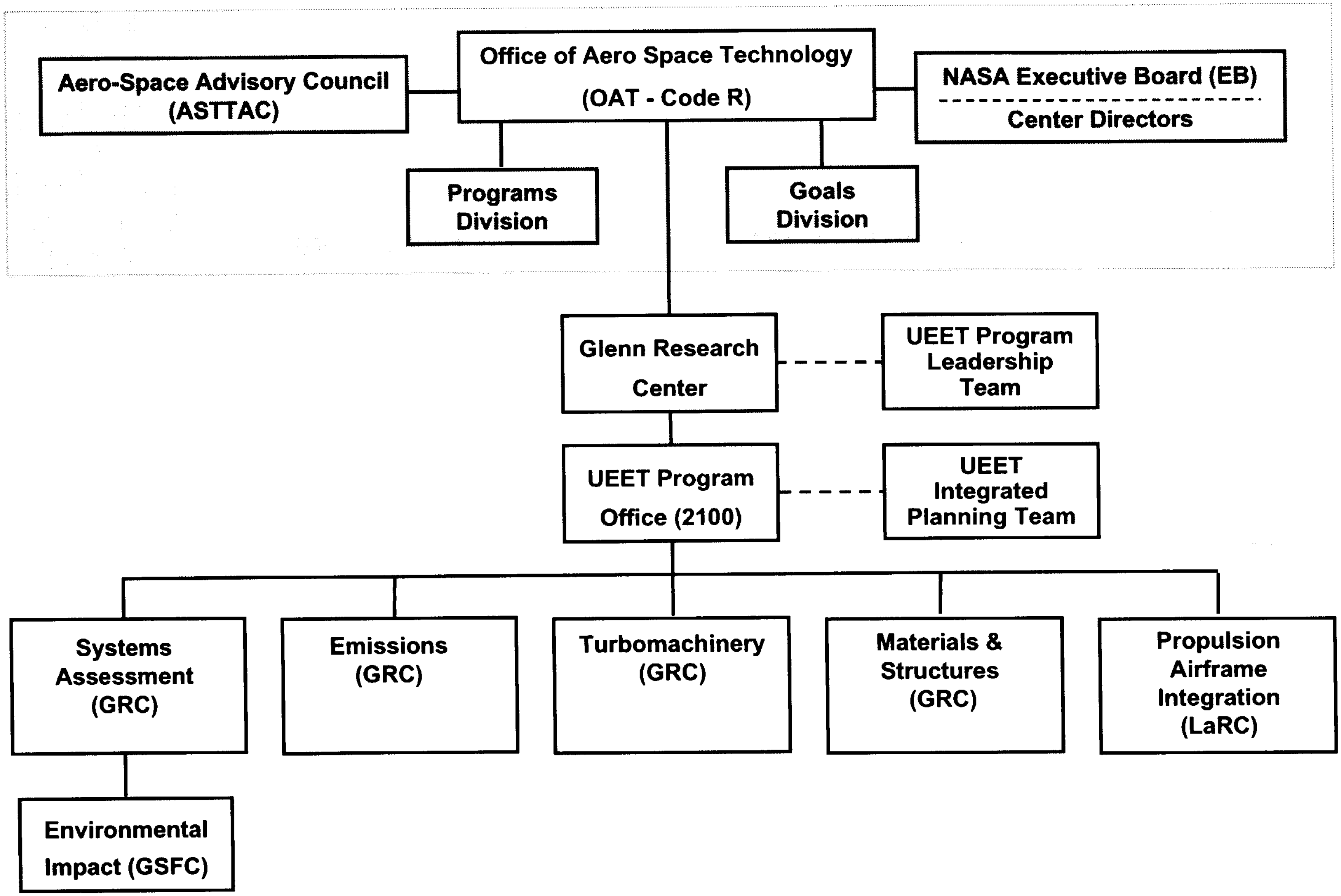
Resource Requirements

Financial

($M)	FY00	FY01	FY02	FY03	FY04	TOTAL
Gross R&D	50.00	50.00	50.00	50.00	50.00	250.00
Net R&D	39.78	40.34	40.57	40.52	40.46	201.67
1.0 Systems Assessment	2.40	3.10	3.30	3.20	3.20	15.20
2.0 Emissions Reduction	13.60	11.44	10.96	9.84	8.56	54.40
3.0 Highly Loaded Turbomachinery	11.40	9.50	11.10	12.90	14.10	59.00
4.0 Materials & Structures for High Performance	9.68	12.20	10.91	10.18	10.20	53.17
5.0 Propulsion Airframe Integration	2.20	3.60	3.80	3.90	3.90	17.40
6.0 Program Management	0.50	0.50	0.50	0.50	0.50	2.50

Industry Contributions ($M)	8.60	6.60	9.45	11.35	9.30	45.30

UEET Program Organization Structure



UEET

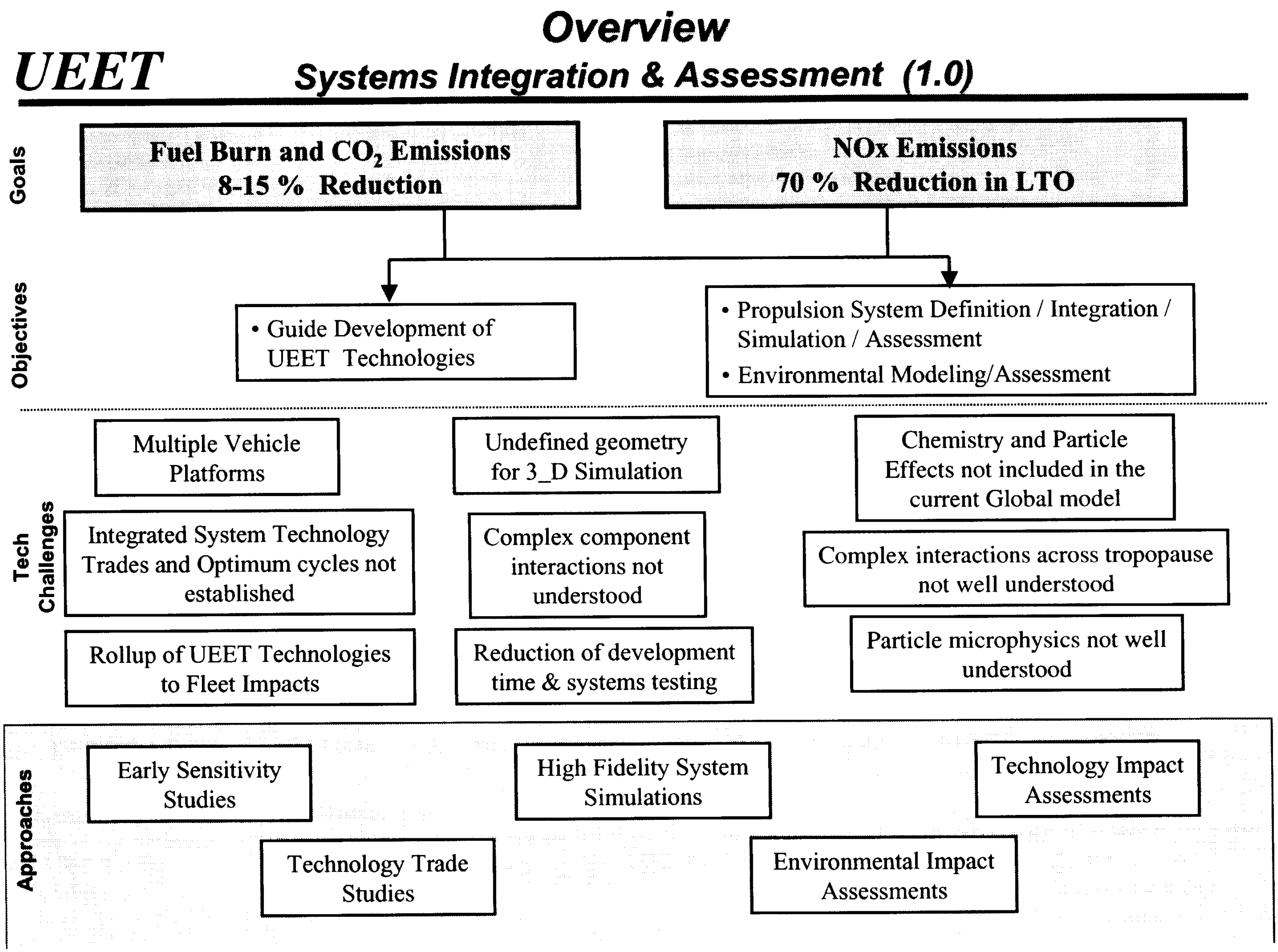
Integrated Planning Team (IPT)

Name	Organization
Joe Shaw	NASA Glenn
Steve Jones	P&W
Fred Krause	GE
Vinod Nangia	Allied Signal
Scott Cruzen	Williams International
Gerry Brines	Allison
Jeff Lewis	Boeing
Don Williams	Lockheed-Martin

Program Management Team

Name	Organization		Responsibility
Joe Shaw	UEET Program Office	GRC 2100	Program Manager
Bob Plencner	High-Speed Systems Office	GRC 2300	Systems Assessment Project Manager (1.0)
John Rohde	Subsonic Systems Office	GRC 2200	Emissions Project Manager (2.0)
Kaz Civinskas	Subsonic Systems Office	GRC 2200	Turbomachinery Project Manager (3.0)
Ajay Misra	High-Speed Systems Office	GRC 2300	Materials and Structures Project Manager (4.0)
Jim Pittman	Aero Performing Center Management Office	LaRC	Propulsion Airframe Project Manager (5.0)

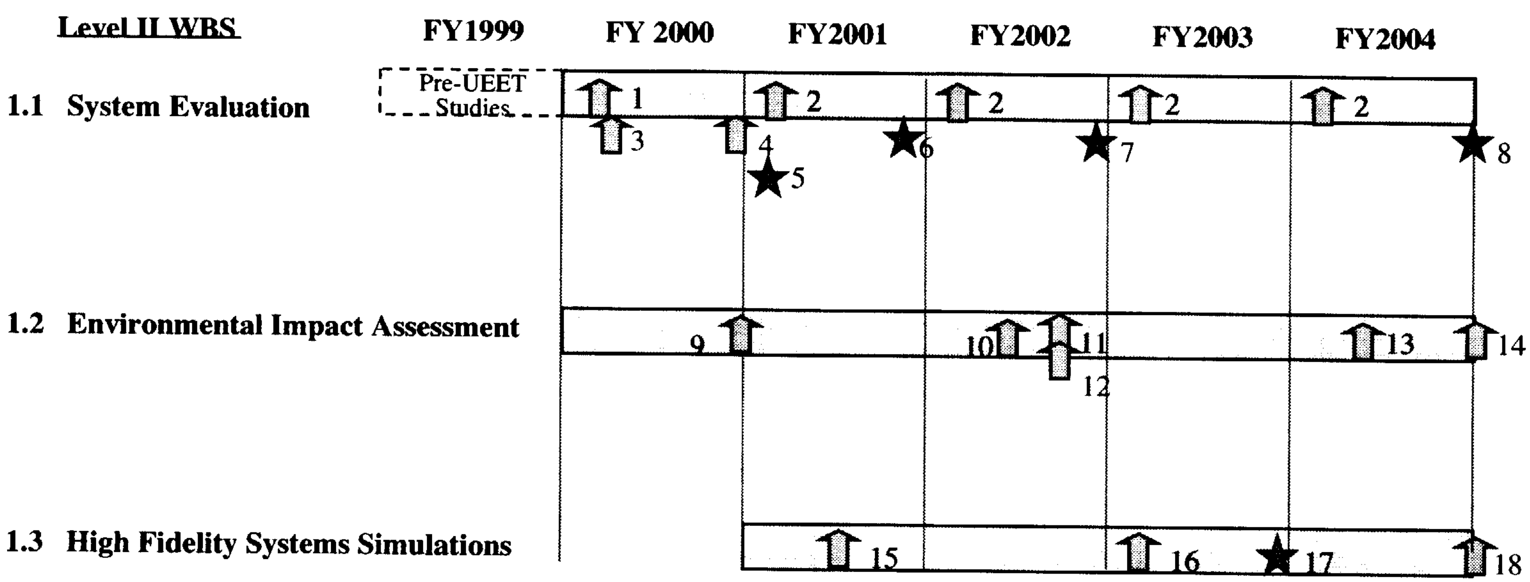
Appendix ⟶


Overview
UEET
Systems Integration & Assessment (1.0)
Goals
Fuel Burn and CO2 Emissions
8-15 % Reduction
NOx Emissions
70 % Reduction in LTO
Objectives
• Guide Development of UEET Technologies
• Propulsion System Definition / Integration / Simulation / Assessment
• Environmental Modeling/Assessment
Tech Challenges
Multiple Vehicle Platforms
Integrated System Technology Trades and Optimum cycles not established
Rollup of UEET Technologies to Fleet Impacts
Undefined geometry for 3_D Simulation
Complex component interactions not understood
Reduction of development time & systems testing
Chemistry and Particle Effects not included in the current Global model
Complex interactions across tropopause not well understood
Particle microphysics not well understood
Approaches
Early Sensitivity Studies
Technology Trade Studies
High Fidelity System Simulations
Environmental Impact Assessments
Technology Impact Assessments

UEET — Level I and II Milestone Schedule

◆ Decision Point
★ Level I Milestone
⇧ Level II Milestone

Systems Integration & Assessment (1.0)



Outputs

- Baseline A/C & Engines
- Propulsion/Mission Sensitivities
- Concept A/C & Engine Definition
- Annual Metric Assessments
- Characterization of Exhaust Products
- Understanding of Atmospheric Impact
- Understanding of Health Impact (Supersonic)
- Conceptual Mechanical Design
- Component Aero/Thermo Interaction

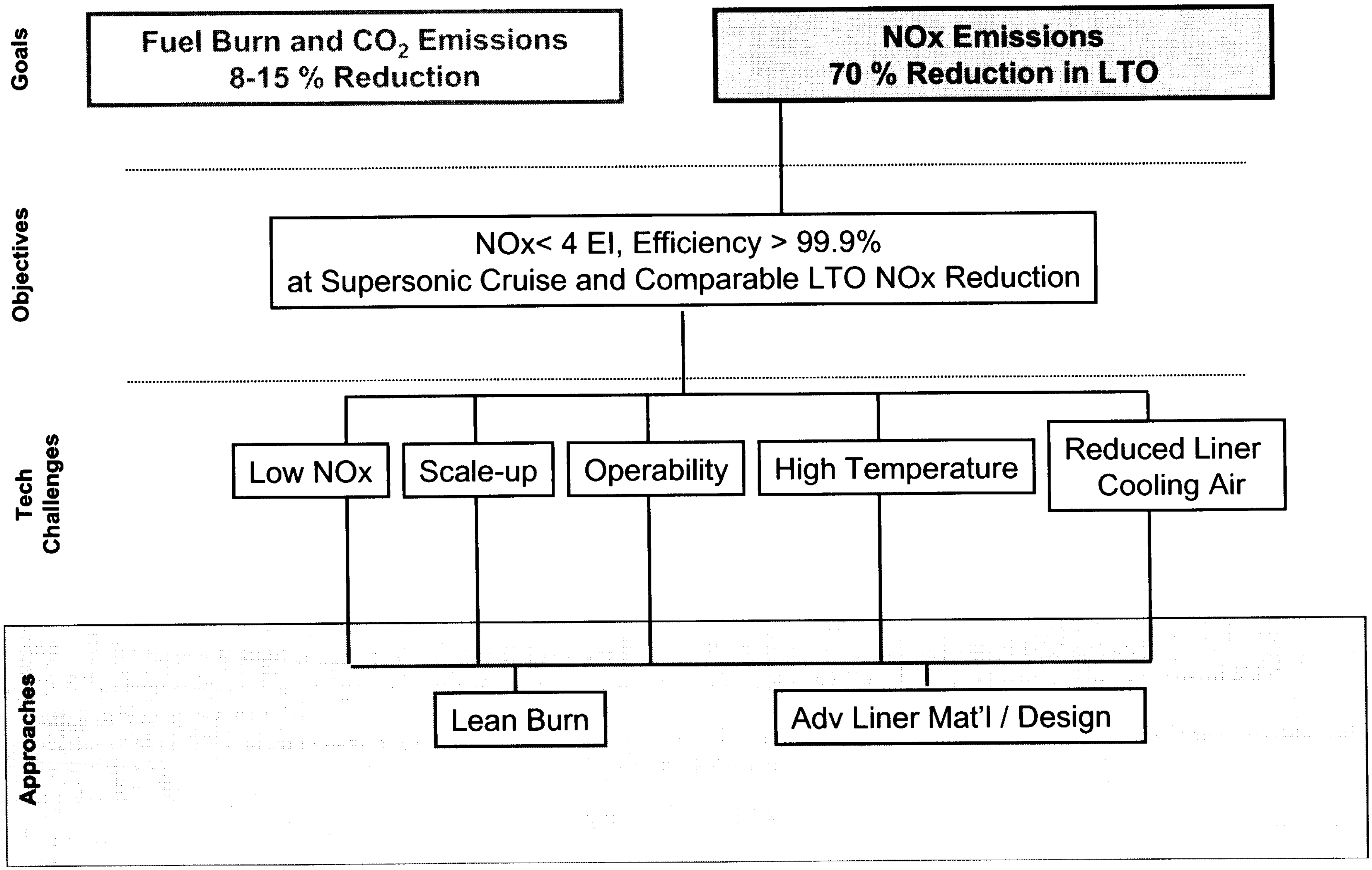
<u>Milestones</u> (*=Level 1)

1. Metric Assessment Process Defined
2. Annual Metrics Assessments
3. Baseline propulsion and airframe tech configs with supporting gross sensitivities (including NOx/CO_2)
4. Preliminary technology trade studies complete
*5. Preliminary Technology Benefits Assessment complete
*6. Propulsion Conceptual Definition
*7. Interim Tech Assessment
*8. Final Technology Assessment
9. Baseline Environmental Impact Assessment
10. Mid-point Emissions Assessment
11. Mid-point Atmospheric Assessment
12. EPA Health Risk Assessment Framework
13. Final Emissions Assessment
14. Final Atmospheric Assessment
15. Selection of system(s) for detailed simulation
16. Conceptual Mechanical Aerodynamic and Thermal Designs
*17. Initial High Fidelity System Simulation (Numeric test cell)
18. Assessment of Numeric Test Cell on Development Time

UEET

Overview
Supersonic

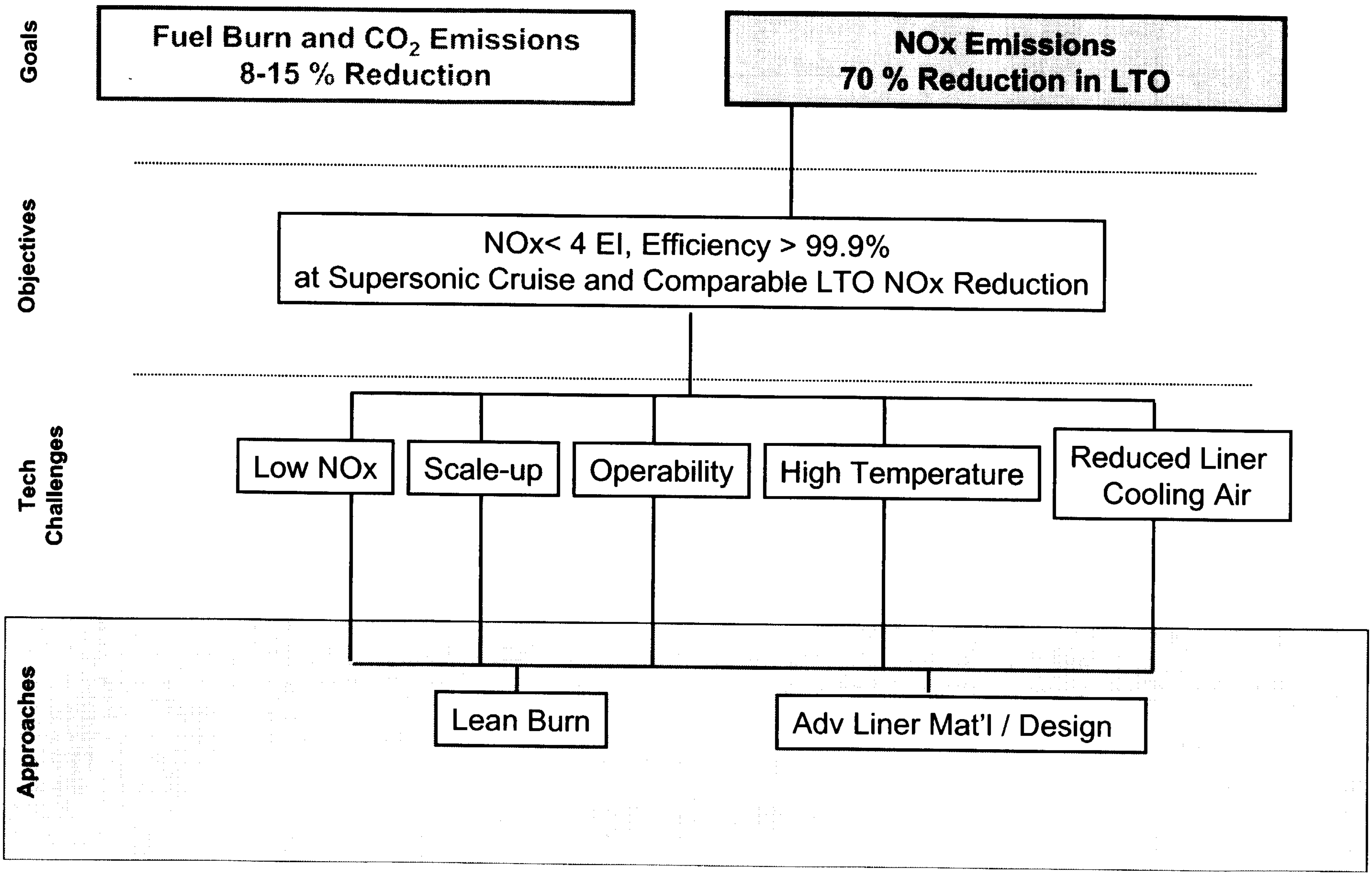
Emissions Reduction (2.0)



UEET

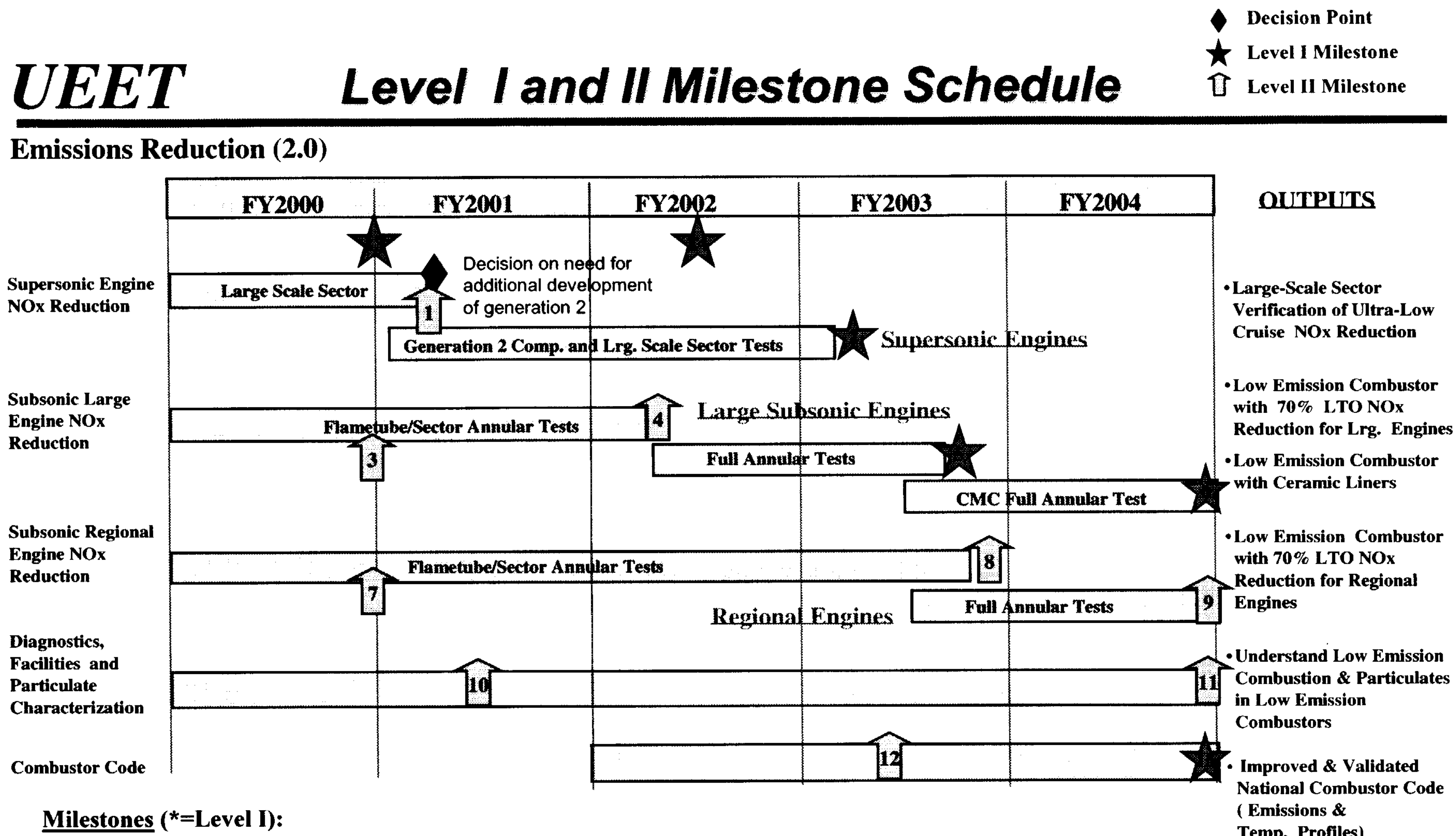
Overview
Supersonic

Emissions Reduction (2.0)



UEET Level I and II Milestone Schedule

Emissions Reduction (2.0)



Milestones (*=Level I):

1 - Init. Lrg. Scale Sector for Supersonic Engines
*2 - Lrg. Scale Sector Verification of Ultra-Low Cruise NOx Combustor
3 - Demo. of 70% LTO Nox Reduction in Flametube for Large Engines
4 - Demo. of 70% LTO NOx Reduction in a Sector Rig for Large Engines
*5 - Demo. of 70% LTO NOx Reduction in a Full Annular Combustor Rig for Large Engines
*6 - Demo. of 2400°F Ceramic Liner in Full Annular Low Emission Combustor
7 - Demo. of 70% LTO Nox Reduction in Flametube for Regional Engines
8 - Demo. of 70% LTO Nox Reduction in Sector for Regional Engines
9 - Demo. of 70% LTO NOx Reduction in a Full Annular Combustor Rig for Regional Engines
10 - Complete Second Leg of Advanced Subsonic Combustion Rig
11 - Establish Understanding of Particulate with Advanced PAGEMS
12 - Init. Assessment of Subsonic Combustor Concepts with the National Combustor Code.
*13 - 70% LTO NOx Reduction Demonstrated in Flametube
*14 - 70% LTO NOx Reduction Demonstrated in Sector Rig
*15 - Physics Based Prediction Codes Validated (Combustors)

UEET Overview

Highly-Loaded Turbomachinery (3.0)

Goals

- **Fuel Burn and CO_2 Emissions 8-15 % Reduction**
- NOx Emissions 70 % Reduction in LTO

Objectives

- **Reduce Component Weight -20%, Engine Weight -5%**
- **Increase Efficiency by 1% to 2%**
- **Increase Average Stage Loading +50%**
- **Increase Turbine Inlet Temperature +400°F at Commercial Life**
- **Reduce Cooling Flow by 25%**

Tech Challenges

- Large fan stage rotor-stator spacing dictated by noise
- High risk for structural integrity of blades
- Flow through blades limited by thickness
- Aero design needs to satisfy all operating conditions
- Minimize cost/complexity of new technology
- Minimize fan/stator interaction noise with reduced spacing
- Execute flow control concepts in 3D design

- Strong interaction of shock and viscous layers
- Increased diffusion in blade rows leads to higher losses without flow control
- Goals require turbomachinery performance beyond current "design space"
- Current design rules lead to low aspect ratios which will tend to increase weight & losses
- Higher aspect ratio at high loading levels susceptible to aeromechanical problems
- Higher loading limited by flow breakdown near endwalls and on blading
- Stability impacted by strong interaction between leakage flows and shocks

- Higher coolant temperature at 55:1 OPR
- Accurate prediction of internal and external heat loads
- Prediction of localized heat transfer effects particularly at edges & tips
- Unsteady effects on film-cooling effectiveness
- High Mach effects between HP and LP turbine stages (shock & mixing losses)
- Adverse flow impact of high-flare interstage duct & LP geometries

Approaches

- Trailing edge blowing to fill wakes and allow close coupling
- Flow management through self-pumping within blade (Aspirated airfoils)
- Endwall and tip leakage flow management
- 3D viscous inverse design

- Physics-based modeling of flow control concepts
- 3D blading (sweep, lean, scallop, etc)
- Multistage 3D viscous CFD (steady & unsteady)
- Active/passive stability control
- Rig tests of flow control concepts in single-stage, multistage, and subsystem configurations

- Physics-based fluid/structural modeling for 3D heat transfer analysis of advanced cooling
- Aspirated LP airfoils
- Flow control for HP/LP turbine interstage ducting
- Rig test of close coupled HP/LP turbine system in dual-spool facility

UEET Level II Milestone Schedule

◆ Decision Point
★ Level I Milestone
⇧ Level II Milestone

Highly-Loaded Turbomachinery (3.0)

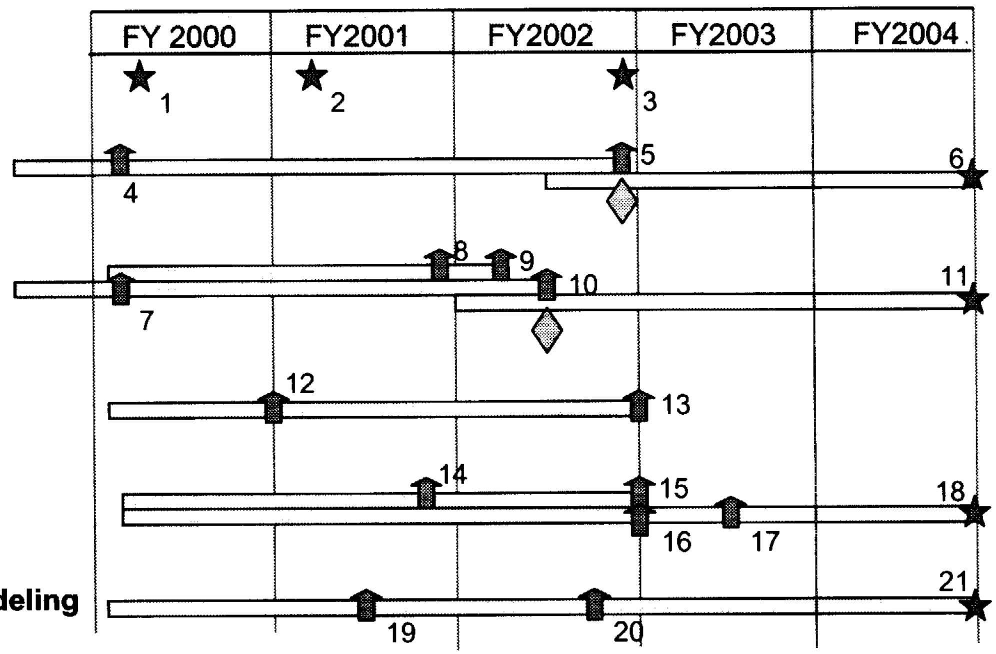
3.1 Reduced Weight Fan

3.2 Multistage Compressors and Fans

3.3 High Efficiency Reduced Cooling HPT

3.4 Ultra-High-Loaded HPT/LPT System

3.5 Flow Physics Based Modeling



OUTPUTS

- Baseline Performance Database
- Blown IGV Performance
- R-S Close Coupling

- Demonstration of Flow Control/Aspiration Concepts in Single-Stages
- Ultra-effective cooling concept
- 55 OPR, 3100Fw/25% less coolant

- Demo. Of Flow Control Concept for LPT

- Multistage/Subsystem Demo. of Ultra-High Aero Loading

- Demo. of Ultra-High Loaded HPT/LPT Subsystem
- 1/3 fewer stages

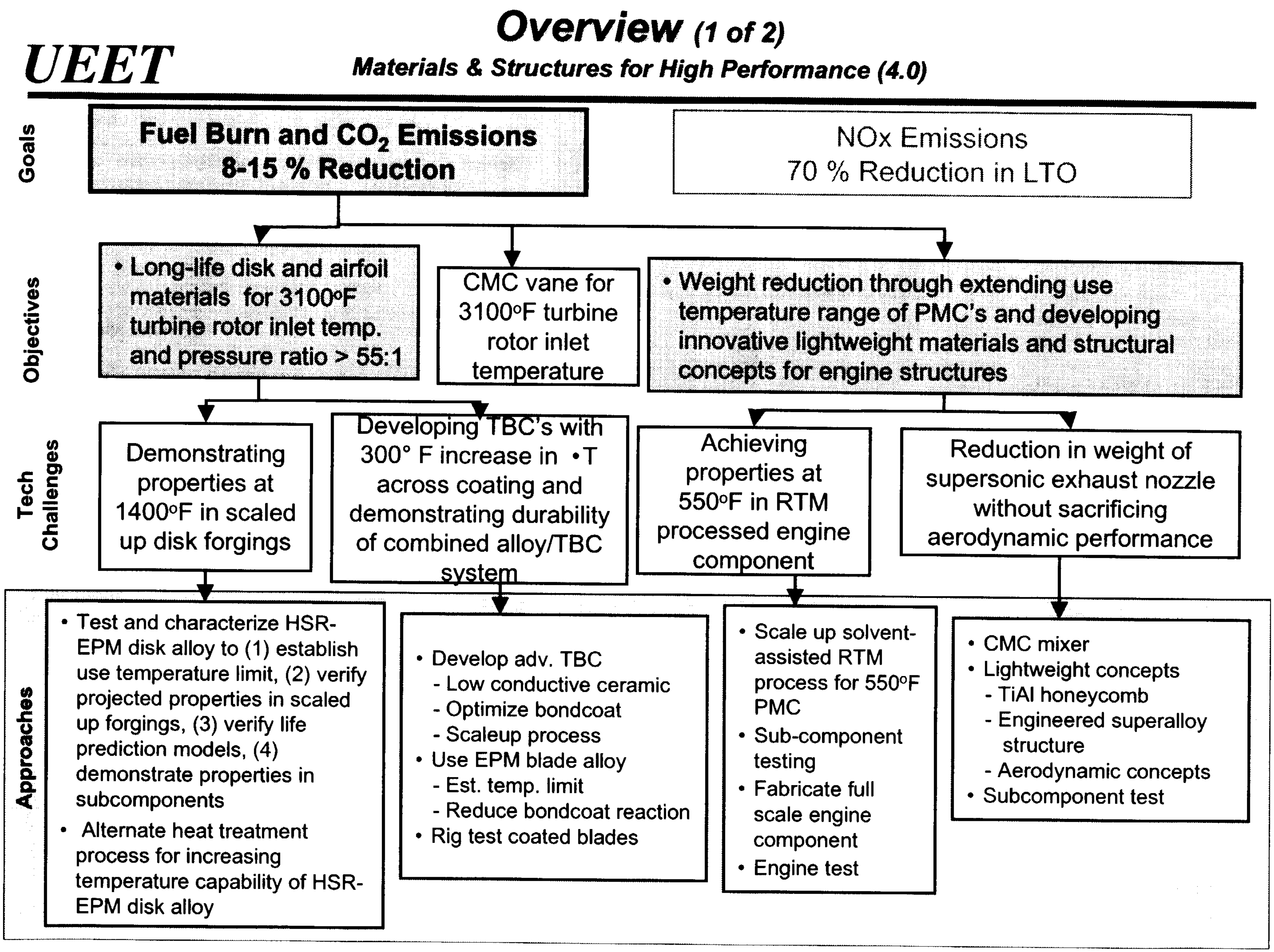
- Physics-Based Prediction Codes

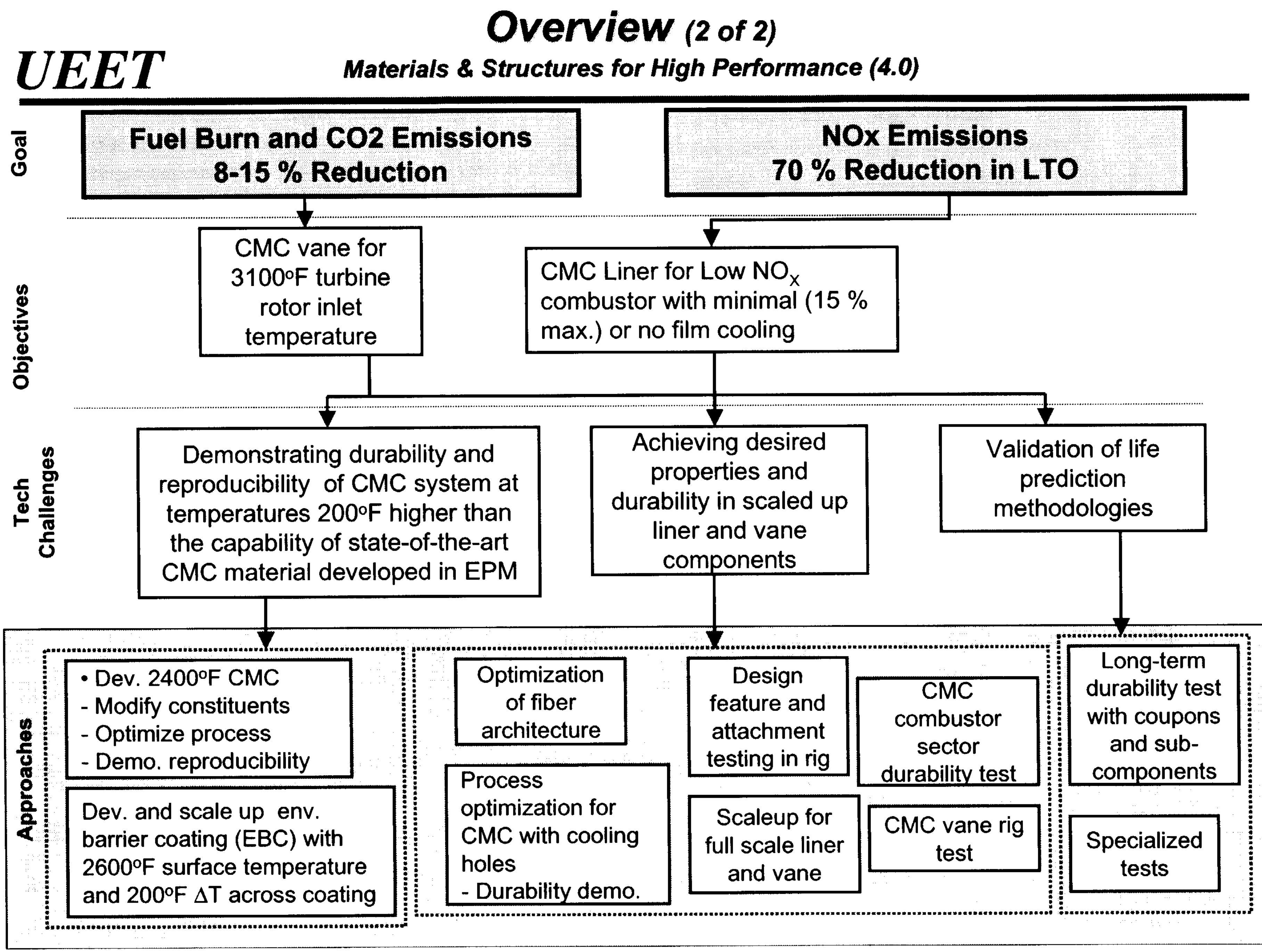
Milestones (*=Level 1):

* 1. Flow Control Concept Selected - Fan, Compressor
* 2. Flow Control Concept Selected - Turbine
* 3. Flow Control POC's
4. LPR Fan Flow Control Concept Defined
5. LPR T.E. Ejection Concept Rig Test (Low Tip Speed Fan)
* 6. Flow Control Validation Test
7. Compressor Flow Control/Aspiration Concept Defined
8. High-Loaded Multistage Performance Baseline Established (HSR 2-Stage)
9. Performance w/Blown IGV T.E. (HSR 2-Stage)
10. Highly-Loaded Flow-Controlled/Aspirated Single-Stage Compressor Test
*11. Multistage Highly-Loaded Rig Test
12. Cooling concept design(s)
13. Rig test evaluation of ultra-effective cooling concept
14. Application to ultra-high-loaded, high-efficiency blading
15. Rig test of ultra-high-loaded stage
16. Counter-rotating dual-spool rig operational
17. Transition duct flow control concept selected
*18. Rig test of highly-loaded, closely-coupled HP/LP turbine stages
19. Flow control models for design developed
20. Completed validated simplified model for particulates
21. Validated Physics-Based Prediction Capability for Design of Ultra-High Loaded Turbomachinery

September 28, 1999
mn_UEETASTAC/PSS

23


UEET
Overview (1 of 2)
Materials & Structures for High Performance (4.0)
Goals
Fuel Burn and CO_2 Emissions 8-15 % Reduction
NOx Emissions 70 % Reduction in LTO
Objectives
• Long-life disk and airfoil materials for 3100°F turbine rotor inlet temp. and pressure ratio > 55:1
CMC vane for 3100°F turbine rotor inlet temperature
• Weight reduction through extending use temperature range of PMC's and developing innovative lightweight materials and structural concepts for engine structures
Tech Challenges
Demonstrating properties at 1400°F in scaled up disk forgings
Developing TBC's with 300° F increase in •T across coating and demonstrating durability of combined alloy/TBC system
Achieving properties at 550°F in RTM processed engine component
Reduction in weight of supersonic exhaust nozzle without sacrificing aerodynamic performance
Approaches
• Test and characterize HSR-EPM disk alloy to (1) establish use temperature limit, (2) verify projected properties in scaled up forgings, (3) verify life prediction models, (4) demonstrate properties in subcomponents
• Alternate heat treatment process for increasing temperature capability of HSR-EPM disk alloy
• Develop adv. TBC
- Low conductive ceramic
- Optimize bondcoat
- Scaleup process
• Use EPM blade alloy
- Est. temp. limit
- Reduce bondcoat reaction
• Rig test coated blades
• Scale up solvent-assisted RTM process for 550°F PMC
• Sub-component testing
• Fabricate full scale engine component
• Engine test
• CMC mixer
• Lightweight concepts
- TiAl honeycomb
- Engineered superalloy structure
- Aerodynamic concepts
• Subcomponent test

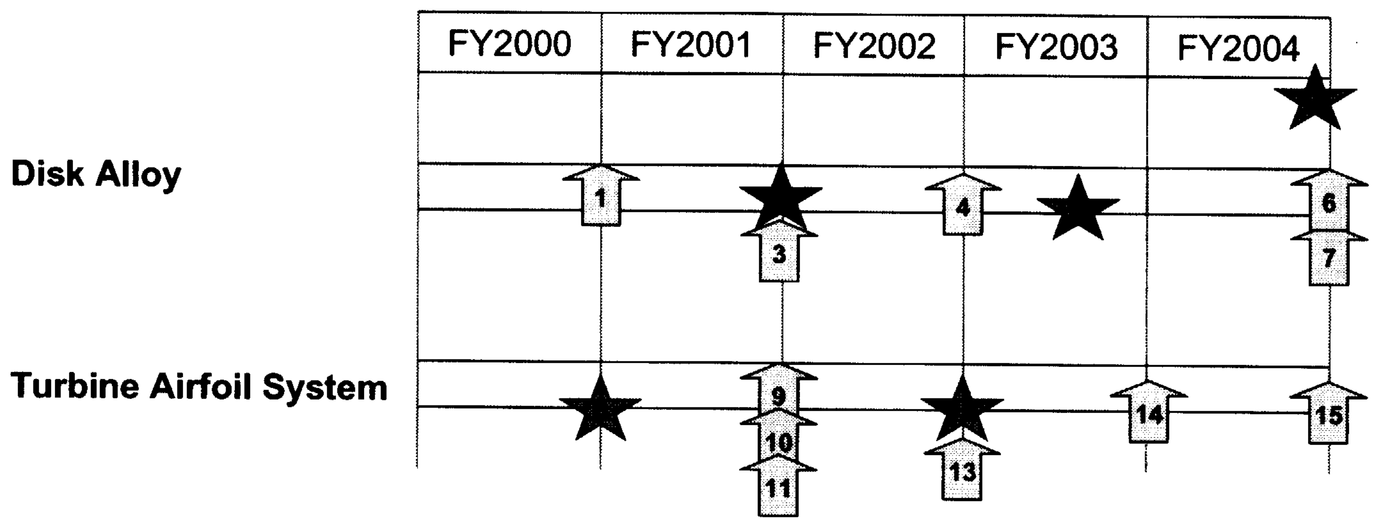

UEET
Overview (2 of 2)
Materials & Structures for High Performance (4.0)
Goal
Objectives
Tech Challenges
Approaches
Fuel Burn and CO2 Emissions
8-15 % Reduction
NOx Emissions
70 % Reduction in LTO
CMC vane for 3100°F turbine rotor inlet temperature
CMC Liner for Low NO_X combustor with minimal (15 % max.) or no film cooling
Demonstrating durability and reproducibility of CMC system at temperatures 200°F higher than the capability of state-of-the-art CMC material developed in EPM
Achieving desired properties and durability in scaled up liner and vane components
Validation of life prediction methodologies
• Dev. 2400°F CMC
- Modify constituents
- Optimize process
- Demo. reproducibility
Dev. and scale up env. barrier coating (EBC) with 2600°F surface temperature and 200°F ΔT across coating
Optimization of fiber architecture
Process optimization for CMC with cooling holes
- Durability demo.
Design feature and attachment testing in rig
Scaleup for full scale liner and vane
CMC combustor sector durability test
CMC vane rig test
Long-term durability test with coupons and sub-components
Specialized tests

UEET

Level II Milestone Schedule

◆ Decision Point
★ Level I Milestone
⇧ Level II Milestone

Materials & Structures for High Performance (4.0)



Outputs

- Demo'd properties in scaled-up HSR-EPM disk alloy at 1350°F
- Processing capability for achieving properties at 1400°F
- Verified probabilistic life prediction model

- Low conductive ceramic TBC composition & process for coating blades
- Optimized alloy/TBC system for 3100°F turbine inlet temperature
- Alloy/TBC combination demo'd in rig tests

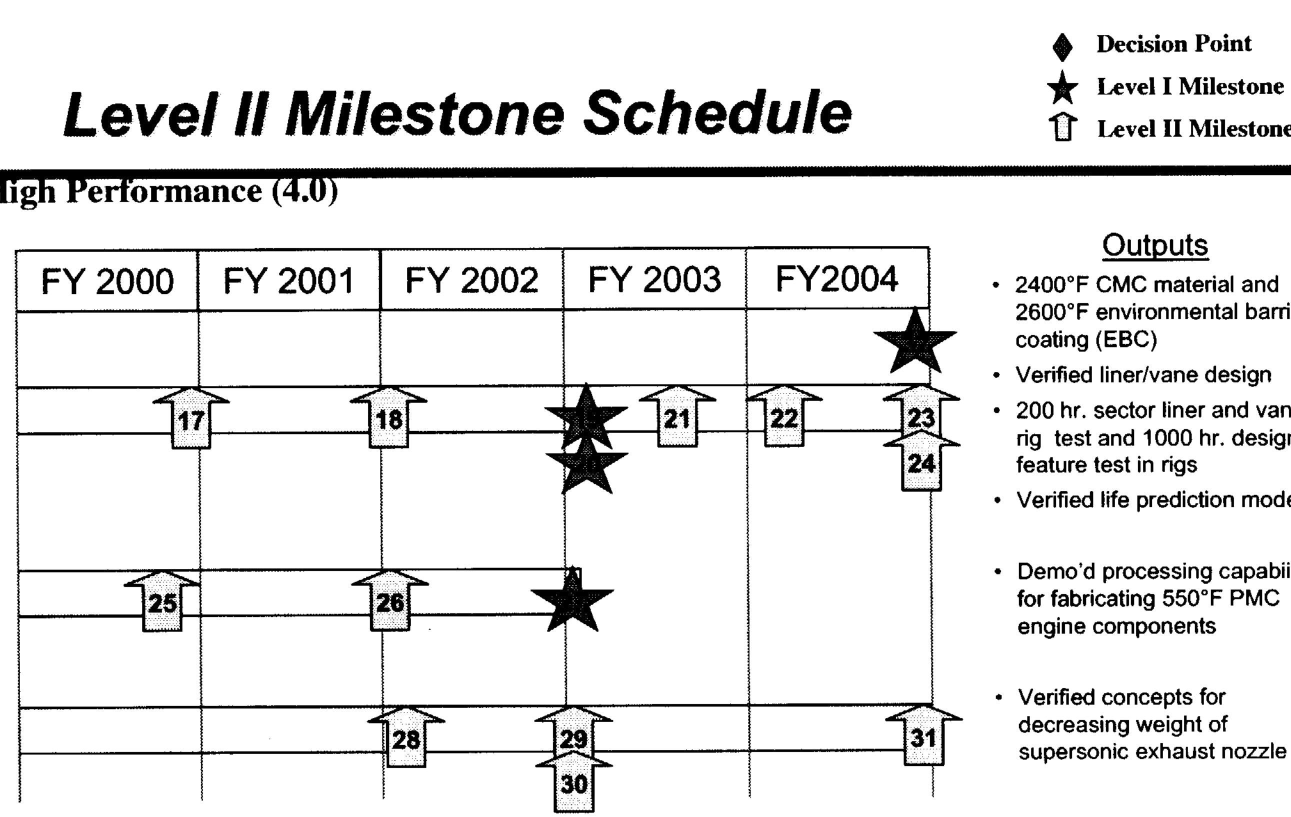
Milestones (*=Level I)

1. Alloy selected for regional engines
* 2. Properties demonstrated in scaled-up forgings for HSR-EPM disk alloy in temperature range of 1350°F
3. Feasibility established for increasing temperature capability of HSR-EPM disk alloy
4. Properties demonstrated in scaled up disk alloy for regional engines
* 5. Process selected for 1400°F disk
6. Properties demonstrated in 1400°F disk
7. Probabilistic disk life prediction model validated
* 8. Low conductive ceramic TBC concepts selected
9. Feasibility of low conductive ceramic TBC established
10. Upper temperature limit established for HSR-EPM blade alloy
11. Bondcoat composition and process optimized
*12. Low conductive ceramic TBC system and process selected
13. Process optimized for preventing alloy-bondcoat interaction
14. Low conductive ceramic TBC process scaled up
15. Rig testing of coated blades complete
16. High Temp. Materials Capabilities Demo. (same as 32 on next chart)

UEET

Level II Milestone Schedule

Materials & Structures for High Performance (4.0)



Outputs

- 2400°F CMC material and 2600°F environmental barrier coating (EBC)
- Verified liner/vane design
- 200 hr. sector liner and vane rig test and 1000 hr. design feature test in rigs
- Verified life prediction models
- Demo'd processing capabiity for fabricating 550°F PMC engine components
- Verified concepts for decreasing weight of supersonic exhaust nozzle

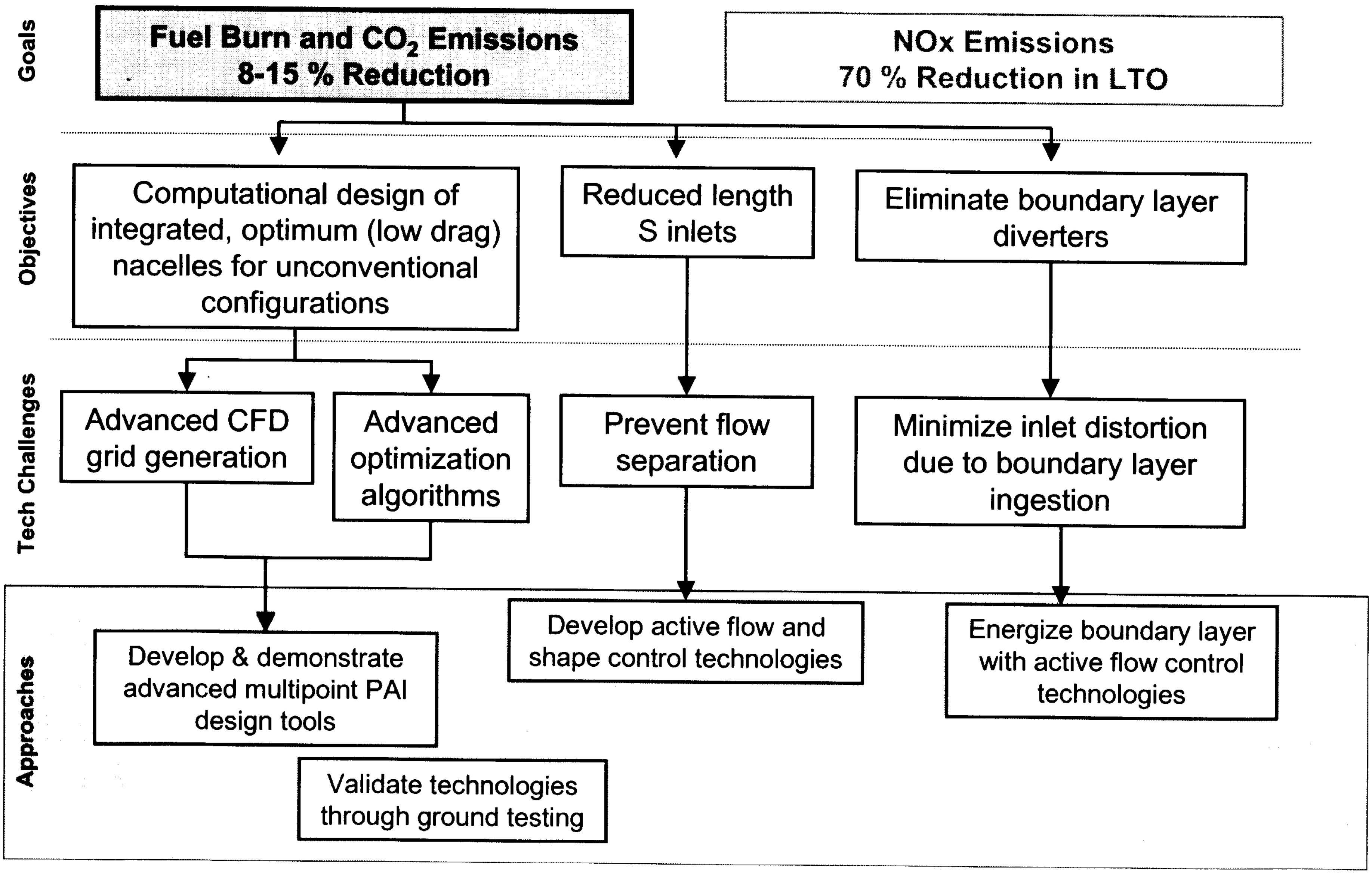
Milestones (*=Level I)

17. Upper temperature limit of HSR-EPM CMC established
18. CMC system developed for combustor liner
*19. CMC combustor liner subcomponent/sector durability demonstrated in rig test for 200 hr.
*20. CMC system developed for turbine vane
21. CMC process scaled up for full scale annular rig test
22. Design features demonstrated for turbine vane
23. CMC vane rig test complete
24. CMC liner subcomponent durability demonstrated for 1000 hr. in rig test
25. PMC resin and process selected for engine component fabrication
26. Engine test ready 550 °F PMC fabrication complete
*27. Engine test complete with 550 °F PMC structure
28. CMC mixer fabrication demonstrated
29. CMC mixer test complete
30. Lightweight materials/structural/aerodynamic concept selected
31. Subcomponent test with adv. lightweight concept complete
32. High Temp. Materials Capabilities Demo (same as 16 on previous chart)

September 28, 1999
mn_UEETASTAC/PSS

27

UEET Overview

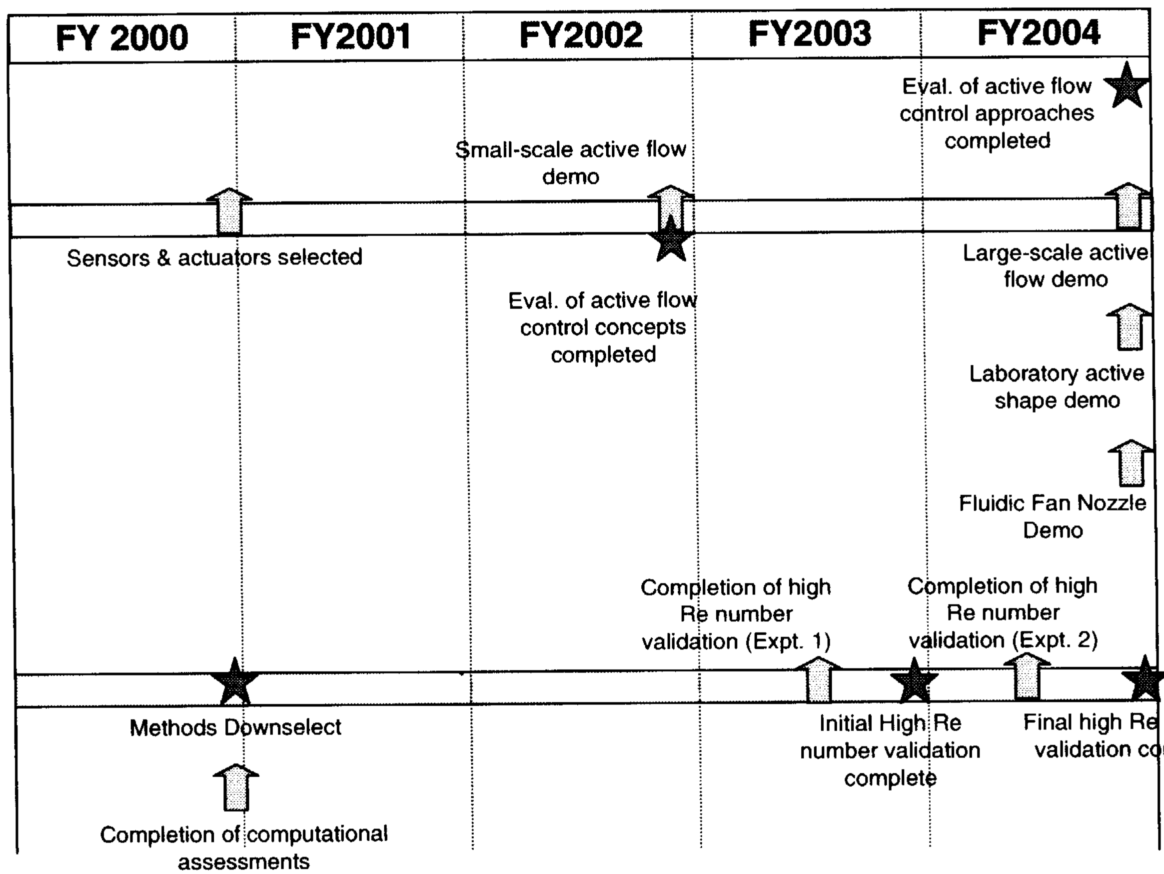


Decision Point
Level I Milestone
Level II Milestone

UEET Level 2 Milestone Schedule

Smart Nacelle Technologies
- **Active Flow Control Inlet**
- **Active Shape Control Inlet**
- **Fluidic Nozzle Area Control**
- **Research methods**

Advanced PAI Concepts
- **Advanced methods**
- **Unconventional Configurations**
- **Wind tunnel validation**



OUTPUTS

- **Demonstration of closed loop active flow control to:**
  - **Energize airframe boundary layer**
  - **Prevent flow separation**
- **Demonstration of closed loop active shape control to:**
  - **Prevent flow separation**
- **Validated, advanced design tools for unconventional configurations**

September 28, 1999
mn_UEETASTAC/PSS