HSR System Integration Studies

NASA Review of FY92 Progress and FY93 Plans

September 23, 1992

Bill Strack - Lewis
Allen Whitehead - Langley
HIGH-SPEED RESEARCH PROGRAM REVIEW

Propulsion System Studies

Outline

• Phase I Program Milestones

• Propulsion System Study Milestone Plan
  -- FY92 accomplishments
  -- FY93 Plans

• Budgets
Major HSCT Propulsion System Issues

1. Which propulsion concept best achieves a balanced compromise of performance, weight, emissions, noise, and complexity?

2. What price do we pay to achieve various levels of environmental acceptability?

3. What are the key uncertainties and what are their potential impacts?
HIGH-SPEED RESEARCH PROGRAM REVIEW

Propulsion System Studies

Phase I Program Milestones
# Propulsion System Studies - Lewis

## Level 2 Summary

**Program Milestones**

<table>
<thead>
<tr>
<th>Date</th>
<th>FY90</th>
<th>FY91</th>
<th>FY92</th>
<th>FY93</th>
<th>FY94</th>
<th>FY95</th>
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<tbody>
<tr>
<td>Propulsion System Down-select</td>
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## Resource Summary (537-01-22)

**Gross R&D**

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<tr>
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<th>FY91</th>
<th>FY92</th>
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**Net R&D**

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<th>FY91</th>
<th>FY92</th>
<th>FY93</th>
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<td>2715</td>
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**Research Contracts**

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<th>FY92</th>
<th>FY93</th>
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**Program Support**

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**CSWY**

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**SSCWY**

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A Propulsion System Down-Select is Needed to Focus the Phase II Technology Program

Oct. '93 Down-Select Decision Gate

Phase I

Environmental Technology Feasibility

Phase II

Propulsion Component Technologies

Primary
Backup

System Studies

Concept 1
Concept 2
Concept 3
Concept N

Monitor Progress
- Shortfall impacts
- Re-direction options
New concept analyses

System Studies
Level 2 HSR Program Schedule - Propulsion System Studies

<table>
<thead>
<tr>
<th>FY 91</th>
<th>FY 92</th>
<th>FY 93</th>
<th>FY 94</th>
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<tbody>
<tr>
<td>GE / PW</td>
<td>Life Study</td>
<td>Evaluations</td>
<td>Assess</td>
</tr>
<tr>
<td>Propulsion Design Studies and Evaluations</td>
<td></td>
<td></td>
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<tr>
<td>NASA Design Studies and Evaluations</td>
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<td>HSR Program Milestone</td>
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<td>Airframer Evaluations</td>
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<td>Net R&amp;D, $K</td>
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</tr>
<tr>
<td>2000</td>
<td>2715</td>
<td>1500</td>
<td>1560</td>
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<tr>
<td>CS + SSC wy</td>
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<tr>
<td>8 + 2</td>
<td>13 + 2</td>
<td>12 + 2</td>
<td>11 + 2</td>
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</table>

Note: Funding excludes airframer evaluation element which is funded by airframe system studies.
HIGH-SPEED RESEARCH PROGRAM REVIEW

Propulsion System Studies

FY92 Accomplishments
# Propulsion System Studies Accomplishments

## FY92 Accomplishment

1. Determined benefits of EPM technology
2. Established / implemented down-select process
3. Completed commercial engine life study
4. Performed comparative analyses of alternative concepts
5. Quantified impact of key uncertainties

## Significance

- Provides quantitative program justification
- Foundation of rationale consensus decision
- Established design rules and EPM requirements
- Critical down-select information
- Provides down-select risk insights
**HSR Enabling Propulsion Materials Program Benefits**

2005 IOC Aircraft meeting Stage 3 noise and $Ei_{NO_x} = 5$ constraints

1991 Engine Materials Technology

<table>
<thead>
<tr>
<th>Airplane gross weight = 720,000 lb</th>
<th>Engine life &lt; 1000 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Combustor Liner with 32% cooling</td>
<td>Conventional Turbomachinery Materials</td>
</tr>
</tbody>
</table>

Metal Exhaust Nozzle with 10% cooling

Max. $T_3 = 1050°F$  
Max. $T_{41} = 2700°F$

2000 Engine Materials Technology

- +6.5% Cruise Efficiency
- -15% Propulsion Weight
- -12% Airplane Weight
- 9,000 - 18,000 hr Engine Life

CMC Combustor Liner with 14% cooling  
Adv. Nickel Alloy Turbomachinery

Intermetallic Exhaust Nozzle with no cooling

Max. $T_3 = 1250°F$  
Max. $T_{41} = 2900°F$
HSR Propulsion System Selection Process

Cycle Optimization and Preliminary Concept Screening (GE/PW, LeRC)

Candidate Concepts
- TBE
- VCE
- MFTF
- Flade
- TBE/IFV

Common Groundrules
- Performance
- Weight / Geometry
- Acoustics
- Cost

Mission Evaluation

Overall Systems Assessment (BAC, DAC, LaRC/ARC)
- Inlet Matching
- Airframe Installations (3)
- Mission Evaluation
- Economic Analysis
- Risk Assessment

Preferred Concept

Data Decks

BAC: 1991

APPROAC2.DRW
WCS/KML 11/27/91
Monte Carlo Simulation Risk Analysis

- Inlet, Engine, Nozzle Components
  - Maintenance Cost
  - Price
  - Weight
  - Efficiency
  - Probability
  - Value

- Propulsion System Forecast
  - Maintenance Cost
  - Price
  - Weight
  - Performance
  - Confidence

- Propulsion System Models
  - (5 Concepts)

- TBE
- MFTF
- VCE
- FLADE
- TBE / IFV

- Direct Operating Cost Model

- Aircraft System Model

Many passes through with random input values.
Mach 2.4 Turbine Bypass Engine Life Study

Design Changes from Military-like STJ949 to HSCT STJ989

- Engine weight increased ~11%
- Engine design groundrules established
- Material requirements identified for achieving life goals (EPM impact)

Limited Distribution
Turbojet Engines
Engine exhaust velocity = 3,200 ft/sec

Unsuppressed Sideline Noise

123 EPNdB

Throttled Engine and Oversized Wing
High-Lift

15-16 dB

Mixer-Ejector Nozzle Suppression System

FAR 36 - Stage III

102.5 EPNdB

Stage IV

Status with Gen. 1 mixer-ejector nozzles and without operational procedure credits
Effect of Exhaust Velocity on Sideline Noise

Sideline Noise, EPNdB

Exhaust Velocity, ft/s

Stage 3

TJ / IFV
Flade
Mixed Flow Turbofan
Variable Cycle Engine

20+ dB problem

TJ

SIDELINE.DRW
WCS/JJ 07/31/92
Status of NASA In-House Comparative Propulsion Studies

Mach 2.4, 100% supersonic 5000 n.mi. range, 292 passengers

Stage III sideline constraint
Assumes material goals and mixer-ejector nozzle goals are achieved
LeRC results as of September, 1992
Key Propulsion System Uncertainties

Technical

1. Adequate mixer-ejector nozzle aero/acoustic performance
   -- oversize engine and/or wing
   -- exclude TBE and low-BPR MFTF

2. EPM materials progress
   -- investigate alternative shortfall strategies

External

3. More severe airport noise regulations
   -- determine economic penalty
   -- identify tolerant concepts

4. Climb noise
   -- determine low climb noise concepts

5. Mach number selection
   -- focus on 2.4
   -- design a few 1.6 and 2.0 engines (sonic boom, emissions, airframe materials)
Impact of Noise Suppression Technology and Noise Constraint

Mach 2.4, all supersonic 5000 n.mi. range, 292 passengers
Cycle, nozzle, wing loading, thrust loading vary along each curve
Ignores aircraft installation differences and possible climb noise constraint
NASA Lewis results as of September 1992

Relative Takeoff Gross Weight

1.15
1.1
1.05
1.0
0.95
0
20
15
10
5
0
Stage III
Stage III - 5

Noise Suppression, dB

- Limited Distribution -
Sensitivity to Nozzle Performance and Weight

Mach 2.4 TBE - Powered HSCT
Reference TOGW: 701,000 lb
Impact of Turbine Inlet Temperature On $E_{I_{NOx}}$ and TOGW
HSR LPP Combustor Technology

$E_{I_{NOx}}$

$T_{41} \, ^{\circ}F$

Goal

Materials Limit

Flame Tube data

2-4% ΔTOGW

1-2% ΔTOGW
Example Fallback Strategies for CMC Combustor Liner Material

**Strategy 1.**
A. Sacrifice life by as much as one-half and replace CMC combustor liners at the 9,000 hour scheduled replacement of rotating hot parts. Impact: $\Delta DOC = +1-1/4\%$.

**Strategy 2.**
B. Double the LPP combustor liner cooling flow to retain life. This would double NOx E1 from 2-1/2 to 5 unless turbine temperature were decreased $\sim 200^\circ F$. Impact: $\Delta TOGW = +2\%$. 
HIGH-SPEED RESEARCH PROGRAM REVIEW

Propulsion System Studies

FY93 Plans
## Propulsion System Studies Planned Accomplishments

### Planned FY93 Accomplishment

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Complete propulsion down-select studies including risk assessments</td>
</tr>
<tr>
<td>2.</td>
<td>Determine impact of &quot;Stage IV&quot; constraint</td>
</tr>
<tr>
<td>3.</td>
<td>Complete turbomachinery noise characterization</td>
</tr>
<tr>
<td>4.</td>
<td>Complete climb noise comparisons</td>
</tr>
<tr>
<td>5.</td>
<td>Complete Lockheed propulsion installation study</td>
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</table>

### Significance

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Provides information required for down-select</td>
</tr>
<tr>
<td></td>
<td>Helps thwart arbitrary rule-making</td>
</tr>
<tr>
<td></td>
<td>Helps select tolerant propulsion concept</td>
</tr>
<tr>
<td></td>
<td>Enables approach noise assessments</td>
</tr>
<tr>
<td></td>
<td>Strengthens down-select and FAR 36 assessment</td>
</tr>
<tr>
<td></td>
<td>Helps select axi or 2-D nozzles and inlets</td>
</tr>
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</table>
**Douglas Propulsion Risk Assessment**

**Objectives:**

1. Define inlet system uncertainties quantitatively
2. Perform overall propulsion system risk assessment for five concepts

![Graphs and Diagrams](image-url)
GE / PW Generation II Mixer-Ejector Nozzle Design-Evaluation

**Objectives:** Evaluate methods of achieving FAR 36 Stage III - 4 dB

**Approach:**
Axi-2D hybrid nozzles - 60% and 80% MFA versions

- mechanical design and weight
- 3D flowpath design
- aero and acoustic performance
- boat-tail drag

2D SLP nozzle with increased suppression treatment

<table>
<thead>
<tr>
<th>TOGW for MFTF Engines</th>
<th>BPR</th>
<th>MFA</th>
<th>Oversize</th>
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<tbody>
<tr>
<td>Generation I</td>
<td>.4</td>
<td>105</td>
<td>engine</td>
</tr>
<tr>
<td>Axi-2D Hybrid</td>
<td>.4</td>
<td>60,80</td>
<td>engine</td>
</tr>
<tr>
<td>2D SLP</td>
<td>.4</td>
<td>?</td>
<td>acoustic treatment</td>
</tr>
</tbody>
</table>

Case A. Stage III
Case B. Stage III - 4
**HSCT Climb Noise Prediction Task**

**Objective:** Make first-order estimates of climb noise for 5 propulsion concepts assuming deployed suppression systems.

**Background:** High specific thrust engines may not be able to achieve adequate climb noise levels. Ability to predict acoustics is minimal.

**Approach:** Analytically predict mixer-ejector nozzle performance and acoustics up to Mach 0.7. Accept error band for acoustics.
Lockheed Propulsion / Airframe Installation Study

- Detailed performance determination
- Configuration optimization
- Axi vs. 2-D nozzle comparison
- Axi vs. 2-D inlet comparison

GE VCE Engines and Nozzles

| Axi | 2-D |

Lockheed Airframe and Inlets

Status:

65% complete (100% by 12-31-92)

Early result:
Wing notch required for inboard diverters
HIGH-SPEED RESEARCH PROGRAM REVIEW

Propulsion System Studies

Budgets
FY92 HSR Propulsion Systems Studies Elements
Propulsion Portion

**Baseline** (2365K)

- GE / PW Mach 2.4 engines / nozzles
  - Net $K: 1200

- GE / PW Mach 1.6 / 2.0 engines / nozzles
  - Net $K: 800

- NASA Mach 2.4 engines and support
  - Net $K: 365

**Augmentation** (350K)

- GE / PW Gen II M-E nozzle design / Stage III - 4 assessment
  - Net $K: 175

- DAC inlet risk and system risk assessments
  - Net $K: 120

- Flade fan aero / mechanical design
  - Net $K: 55

**Notes:**
1. GE / PW and DAC will perform Monte Carlo risk assessments
2. BAC will use traditional risk assessment
3. Stage III - x assessments will be performed by DAC, GE / PW, and NASA

Net $K: 2715
# HSR Propulsion Systems Studies

Airframe Portion (LaRC administered, LeRC technically monitored)

## Mach 2.4

<table>
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<tr>
<th>Boeing - TBE, BAC 2D</th>
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<tbody>
<tr>
<td>MFTF (.4, .7, 1.13 BPR)</td>
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<tr>
<td>TBE / IFV</td>
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<tr>
<td>VCE (.4, .26 BPR)</td>
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<tr>
<td>Flade</td>
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<tr>
<td>Detailed evaluations</td>
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<tr>
<td><strong>Douglas and NASA</strong></td>
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### 1992

- **1992**
  - **J**
  - **F**
  - **M**
  - **A**
  - **M**
  - **J**
  - **J**
  - **A**
  - **S**
  - **O**
  - **N**
  - **D**

### 1993

- **1993**
  - **J**
  - **F**
  - **M**
  - **A**
  - **M**
  - **J**
  - **J**
  - **A**
  - **S**
  - **O**
  - **N**
  - **D**

### Performance, weight, geometry

### Cost data

### Tentative Choices

### Down-Select Choices

## Mach 2.0

- **Boeing - Mach 2.0**
  - **TBE**
  - **Flade**
  - **MFTF**

## Mach 1.6

- **Douglas - Mach 1.6**
  - **MFTF**
  - **Flade**
## Decision Rationale for FY93 Task Prioritization

### Prioritized Tasks

1. Down-select support for airframers
2. Turbomachinery noise characterization
3. Annual meeting support
4. Cycle and PAI support (LeRC)
5. Flade fan aero/mech. design
6. Climb noise comparisons
7. Mixer-ejector nozzle life study
8. In-depth MFTF core life study
9. EPM fallback strategy analysis
10. Incorporate life models in cost code

### Rationale (√ = influences down-select)

- √ Increases fidelity. Insures correct decision.
- √ Could reveal concept discriminators.
- √ Conveys key information and forces interpretation.
- √ Only way for NASA to integrate inlets, engines, nozzles.
- √ Reduces Flade component uncertainties.
- √ Deployed suppression systems (M-E) may be show-stopper
- Reduces risk of wrong material development and IOC delay.
- EPM is high-risk and enabling.
- Increases fidelity of DOC calculations.
### Proposed FY93 HSR Propulsion System Studies Resource Allocation

<table>
<thead>
<tr>
<th><strong>Baseline</strong></th>
<th><strong>Down-Select Specific</strong></th>
<th><strong>Net $K</strong></th>
<th><strong>OGL</strong></th>
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<tr>
<td>1. Down-select support for airframers</td>
<td>✓ GE / PW</td>
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<tr>
<td>- cycle / flowpath analyses - risk assessments</td>
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<td>- inlet distortion tolerance - inlet flow matching</td>
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<td>2. Turbomachinery noise characterization during approach</td>
<td>✓ GE / PW</td>
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<tr>
<td>3. Annual meeting support</td>
<td>✓ GE / PW</td>
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<tr>
<td>4. Cycle and PAI support</td>
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<tr>
<td>5. Flade fan aero/mechanical design</td>
<td>✓ GE</td>
<td>80</td>
<td>85</td>
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<tr>
<td><strong>Overguideline</strong></td>
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<td></td>
<td>1187</td>
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<tr>
<td>6. Climb noise comparisons</td>
<td>✓ GE / PW</td>
<td>360</td>
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</tr>
<tr>
<td>7. Mixer-ejector nozzle life study</td>
<td>GE</td>
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<tr>
<td>8. In-depth MFTF core life study</td>
<td>P&amp;W</td>
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<td>9. EPM fallback strategy analysis</td>
<td>GE</td>
<td>200</td>
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<td>10. Incorporate life models into engine cost code</td>
<td>GE</td>
<td>135</td>
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## MILESTONE STATUS
### HIGH-SPEED RESEARCH PROGRAM
#### RTOP 537-01-22 PROPULSION SYSTEMS STUDIES

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<td><strong>22.1 Propulsion Concepts</strong></td>
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<tr>
<td>Assessment</td>
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<tr>
<td>- Refined Mach 2.4</td>
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<td>- Mach 1.6 &amp; 2.0</td>
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<td>- NASA IH</td>
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<td>Initial Mach 2.4 engine evaluation</td>
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<tr>
<td>completed</td>
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<tr>
<td><strong>22.2 Unique Component Modeling</strong></td>
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<tr>
<td>- Civil Engine Life &amp; Material</td>
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<td>Technology Requirements</td>
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<tr>
<td>Engine weights determined &amp; technology shortfalls identified</td>
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<tr>
<td>- 2D vs. Axi Inlet Evaluation and Flade Inlet Evaluation</td>
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<tr>
<td>Best 2D &amp; 2D concept selections</td>
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<tr>
<td>- 2D vs. Axi Mixer-Ejector Nozzle Evaluation and Flade Nozzle Evaluation</td>
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<tr>
<td>Axi vs. 2D installation analysis complete</td>
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*Activity delayed to FY93

**KEY**
- ▼ PLANNED ACTIVITY
- ▲ SCHEDULED COMPLETION FOR DELAYED ACTIVITY
- ◇ PLANNED OR INCOMPLETE MILESTONE
- ▲ ACTIVITY ACTUAL COMPLETION
- ◇ COMPLETED MILESTONE
### MILESTONE STATUS

**HIGH-SPEED RESEARCH PROGRAM**

**RTOP 537-01-22 PROPULSION SYSTEMS STUDIES**

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<th>Activities</th>
<th>1992</th>
<th>1993</th>
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<tr>
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<td>Oct</td>
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<tr>
<td>22.1 Propulsion Concepts</td>
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<tr>
<td>Assessment</td>
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<tr>
<td>22.2 Unique Component</td>
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<tr>
<td>Modeling</td>
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<tr>
<td>- Flade fan aero/</td>
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<tr>
<td>mech. design</td>
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<td>- Gen. 2 axi and 2D mixer-</td>
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<td>ejector nozzles</td>
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<tr>
<td>(Performance, size,</td>
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<td>weight &amp; noise)</td>
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<td>- Turbomachinery noise</td>
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<td>- Climb noise model</td>
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**KEY**
- ▲ PLANNED ACTIVITY
- ▲ SCHEDULED COMPLETION FOR DELAYED ACTIVITY
- ◇ PLANNED OR INCOMPLETE MILESTONE
- ▼ ACTIVITY ACTUAL COMPLETION
- ■ COMPLETED MILESTONE

*Activity delayed from FY92*
Summary

1. Adequate progress towards Oct. '93 down-select
   -- process defined and established
   -- TBE, MFTF's, TJ/IFV data decks generated
   -- VCE and Flade data decks by Oct. 30th
   -- pace is manpower limited

2. MFTF more forgiving than TBE to M-E nozzle shortfalls/Stg IV

3. Stage III-5 causes 3-7% TOGW penalty

4. Moderate hot-section materials shortfalls appear tolerable

5. FY93 plans limited to down-select issues only