Computer Modeling to Solve Problems with the T-38 Propulsion Modernization Program

U.S. AIR FORCE

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by Randy Wimer
USAF Propulsion Engineer
Co-author: Andy Hall
USAF Propulsion Engineer

Briefing Topics

- Briefing Objective
- Systems Engineering
- T-38 Facts
- T-38 Propulsion Modernization Program (PMP) Background and Hardware Configuration
- T-38 PMP – Three Issues
- Independent Review Team
- Findings:
  - Issue #1 - Engine Bay Overheating
  - Issue #2 - Single Engine Takeoff Speed (SETOS) Performance
  - Issue #3 - J85 Engine Reliability
- Lessons Learned
- Summary

Briefing Objective

Share lessons learned from recent T-38 trainer propulsion modifications

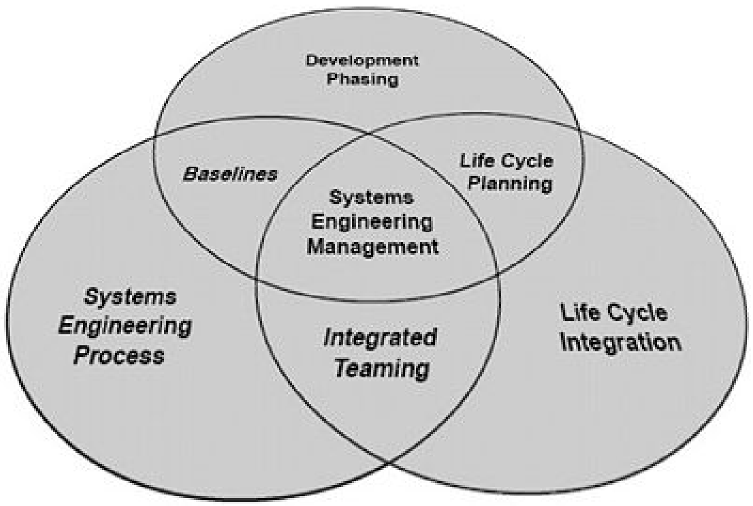
1. Proper systems engineering - early and throughout the program
   - Lack of computer (math) modeling – main tool in solving three unrelated technical problems
2. Integration design authority should be required – both government and contractors
3. Interface Control Document (ICD) should have been used
4. Performance requirements should be included as a contract requirement

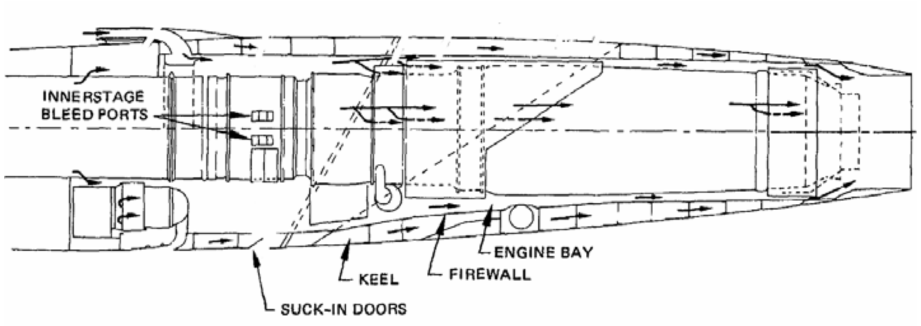
Systems Engineering

- Is an interdisciplinary field of engineering, that focuses on the development and organization of complex artificial systems

- Integrates other disciplines and speciality groups into a team effort, forming a structured development process that proceeds from concept to production to operation and disposal

- Considers both the business and the technical needs of all customers, with the goal of providing a quality product that meets the user needs.



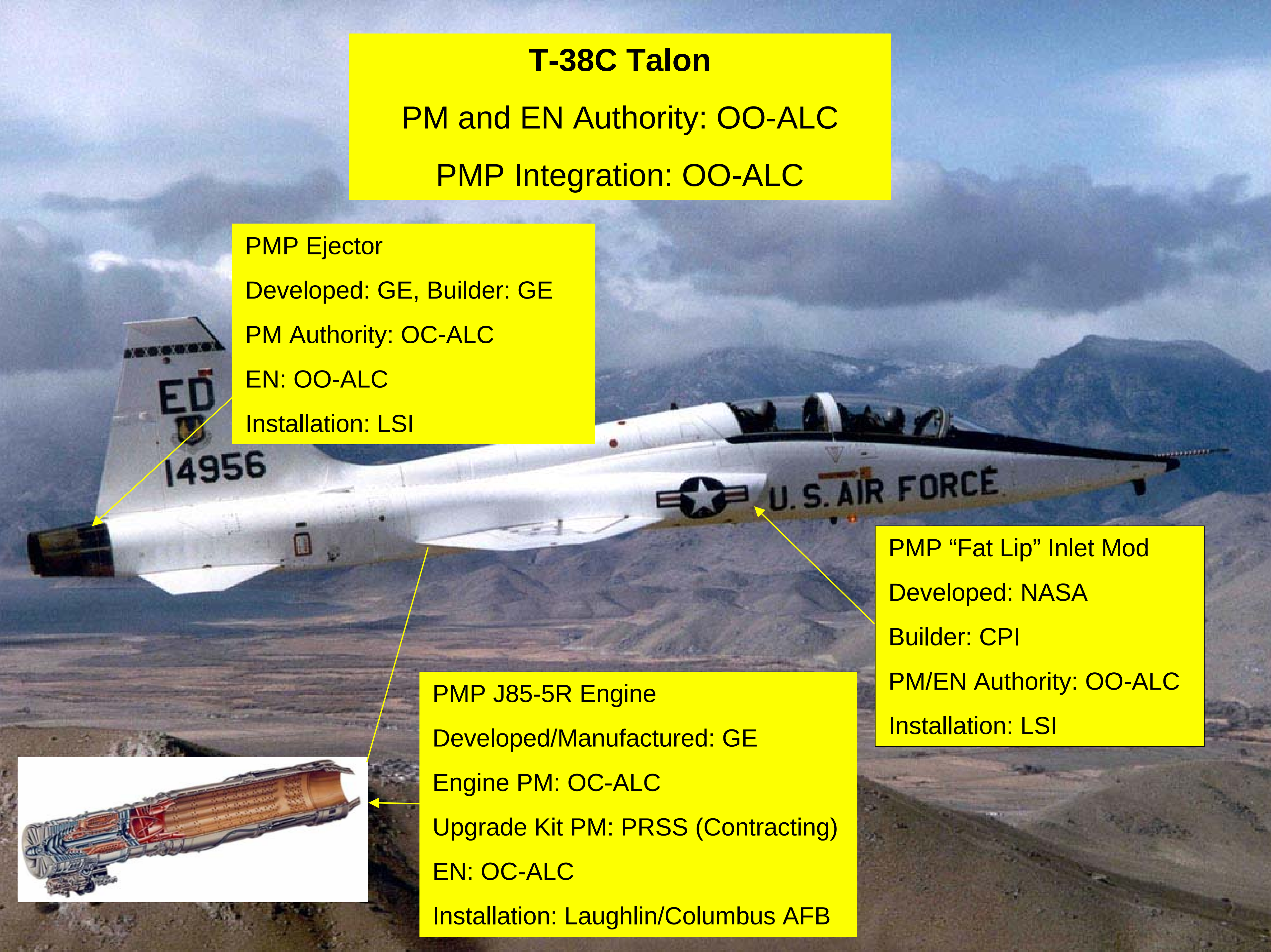


T-38 Facts

- Primary Function: Advanced jet pilot trainer
- Builder: Northrop Corporation
- Engines: Two General Electric J85-GE-5 turbojet engines with afterburners
- Length: 46 feet, 4 inches
- Maximum Takeoff Weight: 12,093 pounds
- Maximum speed: 812 mph (Mach 1.08 at sea level)
- Range: 1,093 miles
- Date Deployed: March 1961
- Production ended: 1972
- USAF Inventory: ~500 (More than 1,100 were delivered to the US Air Force)
- National Aeronautics and Space Administration uses T-38 aircraft as trainers for astronauts and chase planes on programs such as the space shuttle

T-38 Propulsion Modernization Program Background

- Managed by Ogden Air Logistics Center (OO-ALC) at Hill AFB
- 10 Year Contract 2001-2010
- Engine upgrade kit, inlet, ejector
- Aircraft modification at Randolph AFB
  - About 1/3 of USAF fleet modified when independent review team was formed in August 2005
- Government changed ownership and organizational structure 3 times (to date)


T-38C Talon
PM and EN Authority: OO-ALC
PMP Integration: OO-ALC
PMP Ejector
Developed: GE, Builder: GE
PM Authority: OC-ALC
EN: OO-ALC
Installation: LSI
PMP “Fat Lip” Inlet Mod
Developed: NASA
Builder: CPI
PM/EN Authority: OO-ALC
Installation: LSI
PMP J85-5R Engine
Developed/Manufactured: GE
Engine PM: OC-ALC
Upgrade Kit PM: PRSS (Contracting)
EN: OC-ALC
Installation: Laughlin/Columbus AFB
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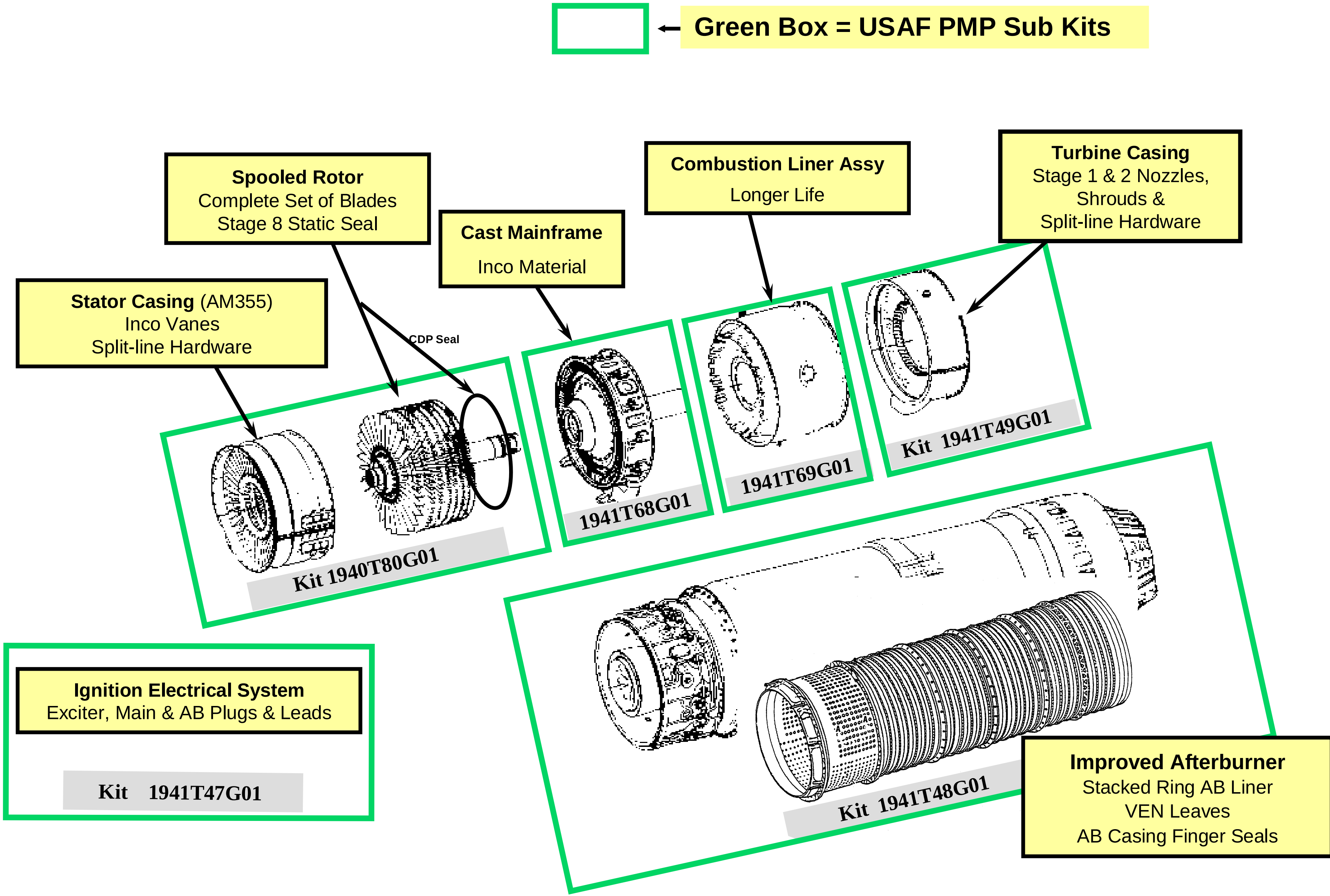
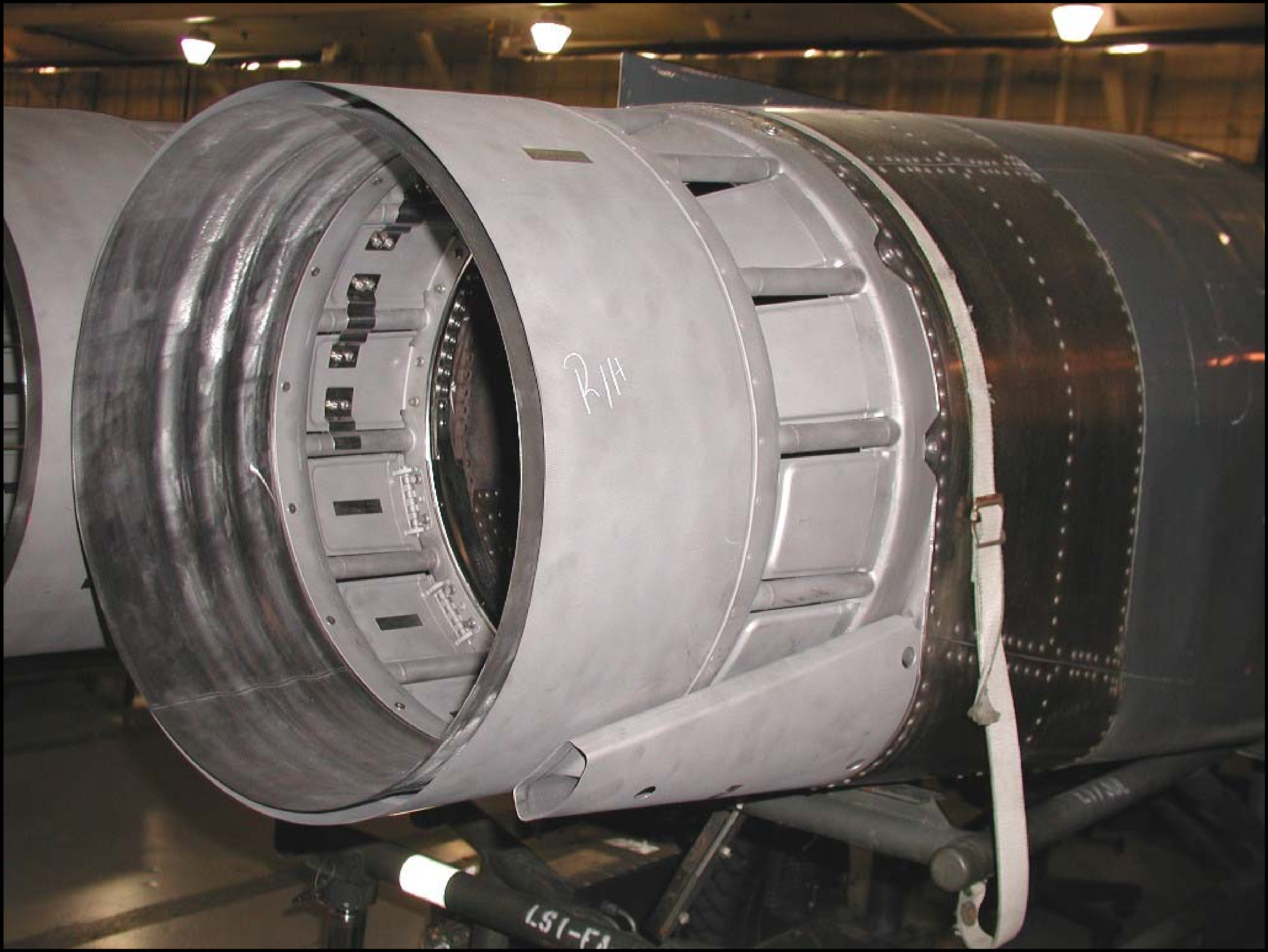
PMP Inlet

GE-J85-5R PMP Engine Kit



J85 PMP Engine

PMP Ejector Nozzle

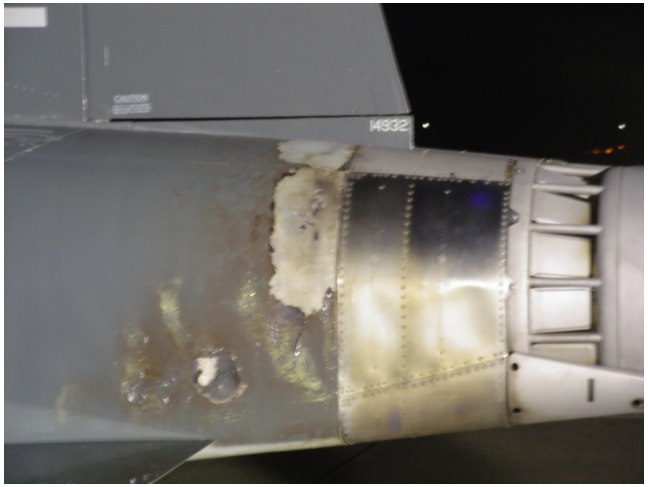


T-38 PMP Upgrade Hangar at Randolph AFB

T-38 PMP Issues

- Three issues arose during initial deployment of PMP aircraft

1. Engine bay overheating



2. Single Engine Takeoff Speed (SETOS) Performance

3. Modified engine did not meet 230 hour Mean Time Between Removals (MTBR) requirement

Independent Review Team

- T-38/J85 IRT (Independent Review Team) formed in August 2005
- Composed of ten USAF senior engineers
  - Support from NASA and contractors
- Purpose was to help solve technical issues with T-38 PMP
- Team held periodic reviews and site visits to GE, Hill AFB, Laughlin AFB, Randolph AFB, and Edwards AFB
- IRT wrapped up in early 2007

T-38 PMP Issue #1– Engine Bay Overheating

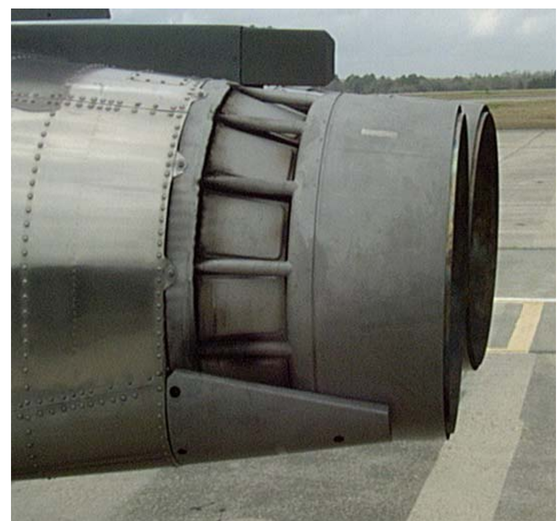
- Two issues: Cockpit engine fire lights and engine bay overheat events
  - 8 Ground Occurrences
  - 32 In Flight Occurrences – all on functional check flights (FCF)

Engine Bay Overheating Cause

- PMP introduced a new inlet and ejector that reduced cooling airflows in engine bays and in keel cooling spaces. This decreased the tolerance of the system to heat-elevating conditions.

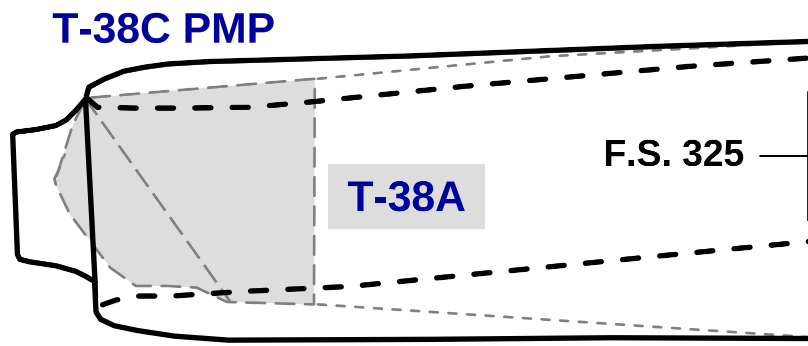
Modified ejector

T-38A



T-38C PMP

T-38A / T-38C Inlet Comparison



T-38A

T-38C PMP

From T-38A to T-38C:

- + 15% capture area
- + 5% throat area

T-38 Boat Tail

Engine Bay with Boat Tail and Engines Removed

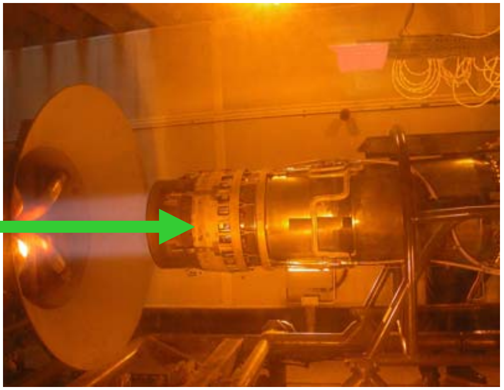
Engine Bay Overheating Findings

- No Single Solution, No Smoking Gun

- System Problem With Multiple Contributions

  - New ejector reduced engine bay cooling airflow
  - New inlet reduced keel cooling airflow
  - Hot air leaks around Variable Exhaust Nozzle (VEN) assembly compounded problem
  - Engine bay cooling degraded over time due to old aircraft ("tired iron") – several leak paths
  - Part to part variability
  - Air framer not initially involved

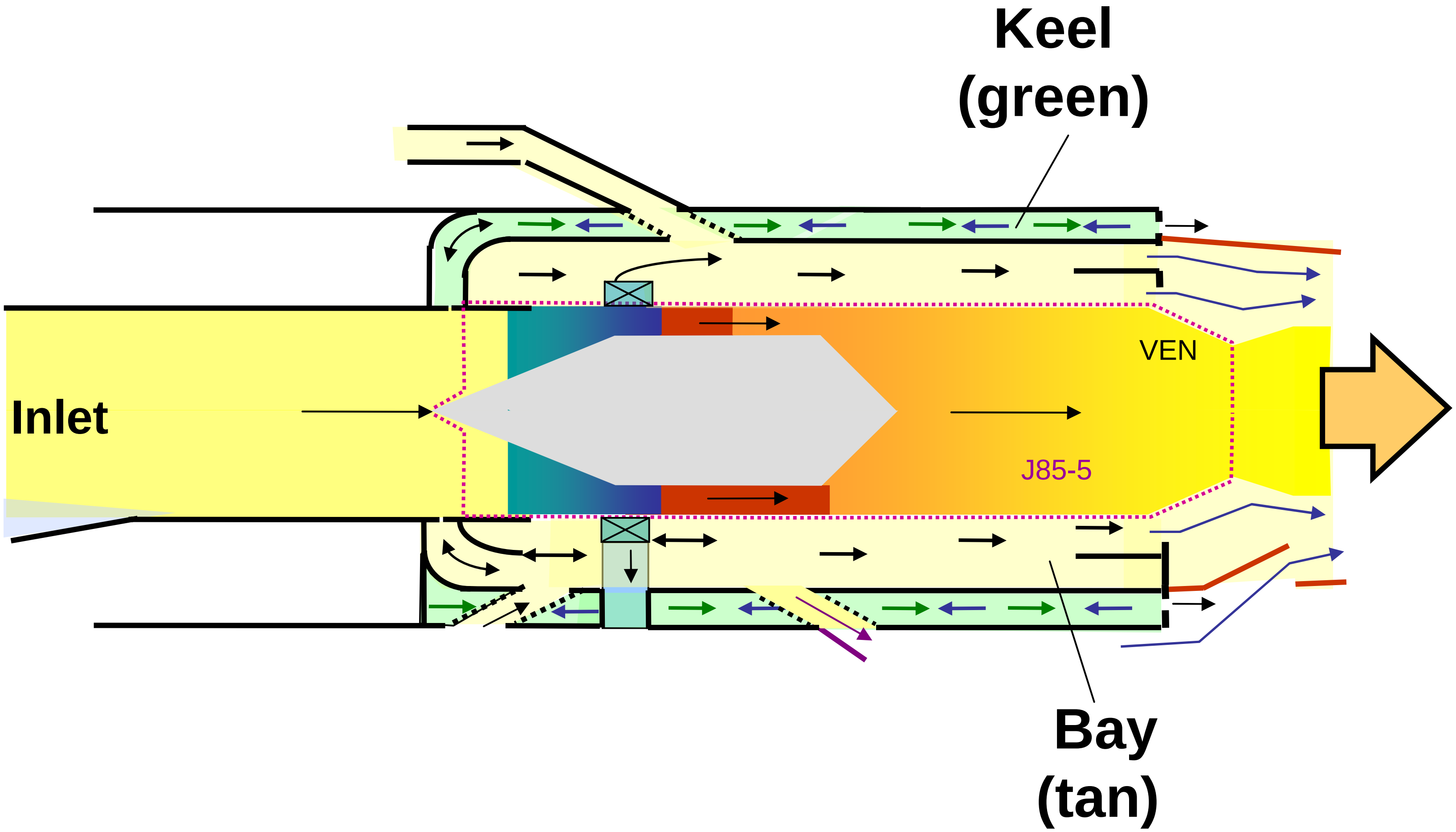
Hot leaks forward of VEN housing



T-38 Boat Tail (Old hardware!)

Engine Bay and Keel Space

Blue arrows indicate keel airflow
reversal under certain conditions



Engine Bay Overheating Approach

- Ground test program – collaborative NASA/USAF/GE effort
  - Aircraft Configuration Effects
  - Engine Variability Effects (VEN Leaks)
- Flight test program at Edwards
- Aero-thermo modeling

IRT Engine Bay Overheating Recommendations

- Validate thermal model in order to determine optimum solution
  - Operational solutions (i.e. different FCF profile) need to be evaluated first and design solutions second
- Recalibrate trigger temperature for fire warning system
- Separate fire safety concerns vs overheat concerns
- Fire safety needs to be determined from validated model and design standards

T-38 PMP Issue #2 - Single Engine Takeoff Speed (SETOS) Performance

- Problem: Lack of confidence by operator that PMP performance threshold was being met

- Operational Requirements Document (ORD) Requirement for hot day takeoff performance: Allow takeoff (12,500lb T-38 with no wind and 1,000 ft pressure altitude at Randolph AFB) at:

  8 degrees F hotter (threshold)

  12 degrees F hotter (objective)

What is SETOS?

- SETOS = Single Engine Takeoff Speed

- The faster of 2-engine takeoff speed

OR

- The speed at which a T-38 should climb at 100 feet per minute
  - Out of ground effect
  - Flaps extended 60 percent (takeoff flaps)
  - Landing gear extended, gear doors closed
  - One engine at MAX, the other windmilling

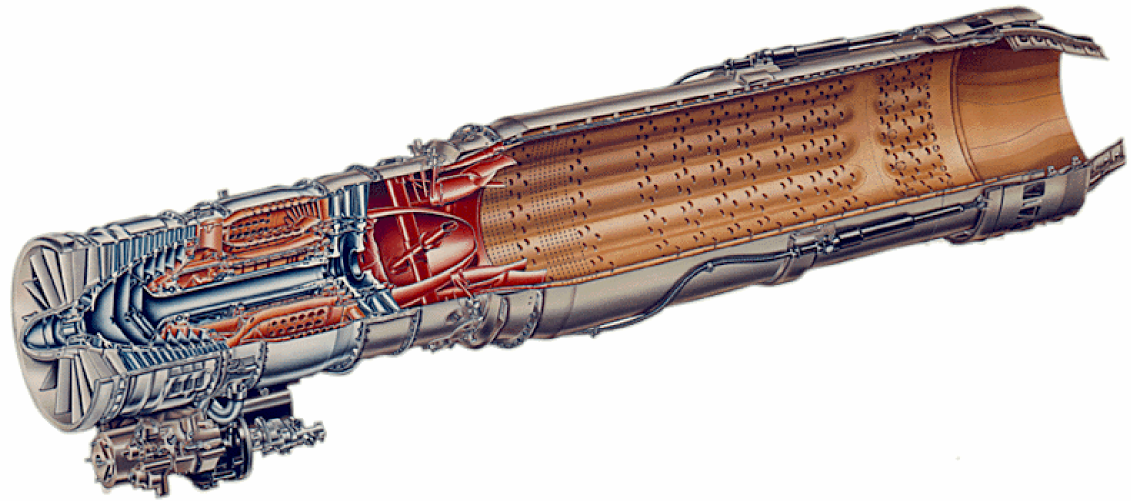
T-38 PMP Issue #2 - Single Engine Takeoff Speed (SETOS) Performance

- Physics:
  - PMP inlet has improved inlet recovery at takeoff conditions
  - Initial flight testing and data analysis did not adequately verify improvement (inadequate modeling)
  - Initial contractor model could not be calibrated
  - Edwards AFB created a performance model and conducted more flight test, verifying the takeoff thrust improvement
  - No wind tunnel testing done
  - Measured thrust minus drag acceleration in flight testing and engine model – used to develop and validate the full scale aircraft drag polars
  - Aircraft performance models included not only engine net thrust but also inlet recovery, boat tail drag, inlet spillage drag, and secondary airflow ram drag and their engine power setting dependencies

T-38 PMP Issue #2 - Single Engine Takeoff Speed (SETOS) Performance

- Model:
  - Updated USAF aircraft performance model
  - Confirmed new model's ability to predict takeoff performance
- Flight test data and analysis show SETOS requirements met or exceeded
- Findings:
  - ORD requirement to improve hot day takeoff performance has been achieved. Improved threshold by 17 degrees F
- IRT also recommended that contractor create up to date aircraft performance model for T-38C PMP aircraft configuration

T-38 PMP Issue #3 - J85 Engine Reliability



J85 engine did not meet 230-hour Mean Time Between Removals (MTBR) Operational Requirements Document (ORD) threshold

- Constant at 155 hours
- PMP upgrade focus was meeting maintenance intervals and shop cost reduction
- Will never get to 230 hours without additional work (never put on contract)
  - Engine controls not improved
- Maintenance model did not exist

T-38 PMP Issue #3 - J85 Engine Reliability

- USAF did not include MTBR requirement on GE contract
- Root Cause:
  - PMP engine MTBR currently same as legacy engine
  - Majority of removals are Unscheduled Engine Removals (UERs) - 86%. Top UER drivers are accessories and quick engine change (QEC) items (e. g. fuel flow transmitter)

Findings - J85 Engine Reliability

- Solution: A J85 maintenance model was Applied to the J85 engine
- Recommendations:
  - Replace gear boxes with rebuilt units which have fuel pumps and fuel controls with design improvements
  - Improve igniter system
  - Implement ASAP to maximize return on investment
  - Investigate use of contractor performance base logistics (PBL)

Lessons Learned

1. Proper systems engineering early and throughout the program
2. Integration design authority should be required
3. Interface Control Document should be used
4. Performance requirements should be included as a contract requirement

Lessons Learned

5. Use of computer (math) modeling
   - Modeling did not exist for all 3 issues
     - -- Engine Bay Flow - model created
     - -- SETOS - model used to extrapolate flight test results
     - -- Engine Reliability – Existing model applied to J85 engine
   - Airplane designed over 40 years ago
     - -- Updated models needed
       - -- Part variability

Summary

- USAF did not use adequate systems engineering for T-38 PMP
  - Five major lessons learned
- IRT formed to assist in solving three technical issues
- PMP continuing to upgrade T-38 trainers

T-38C