Space Transportation Propulsion Technology Symposium
NASA DEVELOPMENT MANUFACTURING & CERTIFICATION PSU



# LIQUID ROCKET ENGINE FLIGHT CERTIFICATION

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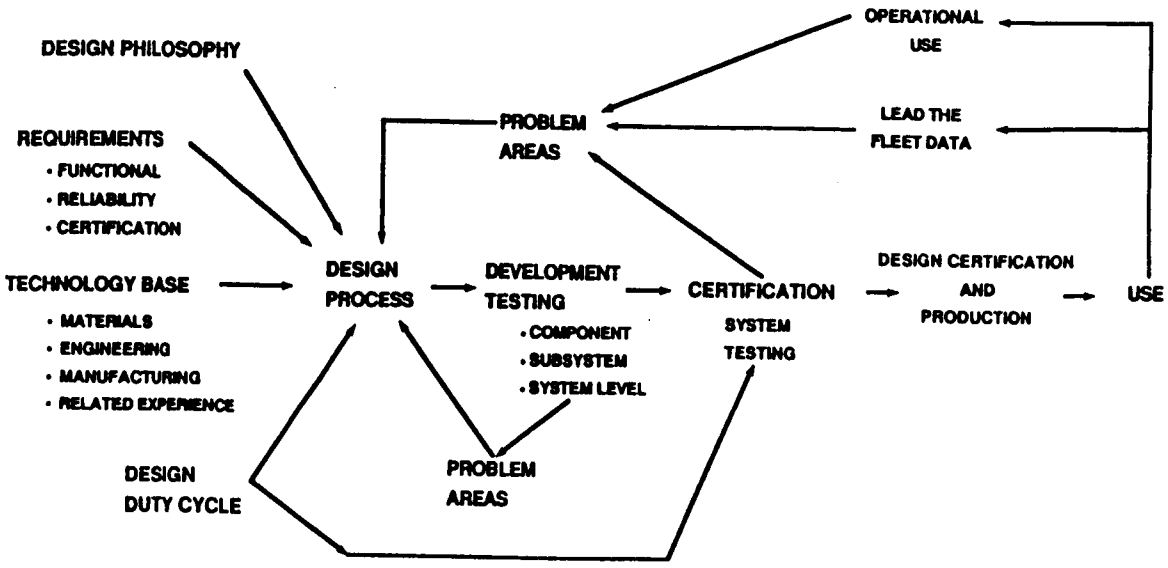
## FLIGHT CERTIFICATION DEFINITION

**THE METHODOLOGY AND PROCESS BY WHICH WE GAIN THE CONFIDENCE TO FLY INCLUDING:**

- DESIGN METHODOLOGY
- ANALYSIS
- COMPONENT TEST
- SUBSYSTEM TEST
- SYSTEM DEVELOPMENT TEST
- SYSTEM CERTIFICATION TEST




# CERTIFICATION ISSUES

- NO INDUSTRY/GOVERNMENT WIDE RECOGNIZED RULES/REQUIREMENTS
  - RULES AND REQUIREMENTS SET BY INDIVIDUAL AGENCIES AND BY INDIVIDUAL PROGRAMS WITHIN AGENCIES
  - PROCESSES ARE HISTORICALLY BASED AND HEURISTIC
- HEAVILY DEPENDENT ON EXPENSIVE AND TIME CONSUMING TEST PROGRAMS
- NO QUANTIFICATION OF ENGINE RELIABILITY
- LITTLE CERTIFICATION AT COMPONENT LEVEL
- NO EXISTING "SPACE BASED" ENGINE CRITERIA

# ENGINE CHARACTERISTICS

| ENGINE | THRUST (LBF) | ISP (SEC) | WEIGHT (LB) | THRUST TO WEIGHT | MIXTURE RATIO (O/F) | CHAMBER PRESSURE (PSIA) | FLT REUSE | THROTTLE | O2/H2 | O2/HC | AIR/HC | N2O4/HDZ | GAS GEN | EXPANDER | STAGE COM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SSME | 488,800 | 452.9 | 7,004 | 69.79 | 6.026 | 3,126 | X | X | X | | | | | | X |
| F-1 | 1,748,200 | 304.1 | 18,616 | 93.91 | 2.27 | 982 | | | | X | | | X | | |
| J-2 | 230,000 | 425.0 | 3,454 | 66.59 | 5.5 | 780 | | * | X | | | | X | | |
| RL-10 | 16,500 | 444.4 | 305 | 54.10 | 5.0# | 465 | | * | X | | | | | X | |
| LR87 | 529,000 | 298.0 | 4,530 | 116.78 | 1.905 | 827 | | | | | | X | X | | |
| LR91 | 103,320 | 314.0 | 1,260 | 82.00 | 1.770 | 827 | | | | | | X | X | | |
| JET+ (TYP) | 15,000 | ++ | 2,500 | 6.00 | N/A | **400 | X | X | | | X | | | | |

* J-2 THROTTLED MIXTURE RATIO BETWEEN 4.5 TO 5.5
RL-10 THROTTLED MIXTURE RATIO BETWEEN 4.3 TO 5.7
** BURNER PRESSURE
# MIXTURE RATIO IS 6.0 FOR SHUTTLE CENTAUR
\+ TYPICAL FIGHTER ENGINE
++ EQUILVALENT Isp : CRUISE POWER 64 SEC AIR AND FUEL, 5100 SEC FUEL ONLY
AUGMENTOR POWER 99 SEC AIR AND FUEL, 1700 SEC FUEL ONLY

# ENGINE DESIGN AND MISSION REQUIREMENTS

| ENGINE | DESIGN STARTS | DESIGN LIFE | MISSIONS | MISSION STARTS | MISSION NOM TIME |
|---|---|---|---|---|---|
| SSME | 55 | 27,000 S | 55 | 1 | 520 S |
| F-1 | 20 | 2,250 S | 1 | 1 | 165 S |
| J-2 | 30 | 3,750 S | 1 | 1 | 380 S |
| | | | | 2* | 150 S* |
| | | | | | 350 S* |
| RL-10 | 20 | 4,500 S | 1 | 2 | 700 S |
| LR87 | 12 | 1,980 S | 1 | 1 | 165 S |
| LR91 | 12 | 2,700 S | 1 | 1 | 225 S |
| JET** | | | | | |
| HOT PARTS | 1,600 | 2,200 H | 1,500 | 1 | 2 H |
| COLD PARTS | 3,200 | 4,400 H | 3,000 | 1 | 2 H |

* S-IVB Stage (First Burn & Restart)
** TYPICAL FIGHTER ENGINE

# STRUCTURAL DESIGN CRITERIA

| DESIGN CRITERIA | SSME | F-1 | J-2 | JET | RL-10 | LR87 | LR91 |
|---|---|---|---|---|---|---|---|
| DESIGN LOADS | | | | | | | |
| o WORST CASE | X | X | X | X | X | X | X |
| o STATIC CONTRIBUTORS | X | X | X | X | X | X | X |
| - 3 SIGMA LEVEL | X | X | X | X | | | |
| - 2 SIGMA LEVEL | | | | | X | | |
| o DYNAMIC CONTRIBUTORS | X | | | X | X | X | X |
| MATERIAL PROPERTIES | | | | | | | |
| o MINIMUM | X | X | X | X | X | X | X |
| GEOMETRY | | | | | | | |
| o MINIMUM | X | X | X | X | X | X | X |

# STRUCTURAL DESIGN FACTORS OF SAFETY

| DESIGN FACTOR | SSME | F-1 | J-2 | JET | RL-10 | LR87 | LR91 |
|---|---|---|---|---|---|---|---|
| ULTIMATE STRENGTH | 1.4 | 1.5 | 1.5 | 1.5 | 1.5 | 1.4 | 1.4 |
| YIELD STRENGTH | 1.1 | 1.1 | 1.1 | * | * | 1.0 | 1.0 |
| PROOF REQUIREMENT | 1.2 | 1.2 | 1.2 | * | 1.2 | 1.2 | 1.2 |
| LOW CYCLE FATIGUE | 4 X DSL | * | * | 2 X DSL | * | * | * |
| HIGH CYCLE FATIGUE | 10 X DSL | * | * | (1) | * | * | * |

NOTES: (*) NO SPECIFICATION REQUIREMENT
DSL = DESIGN SERVICE LIFE
(1) JET DESIGNED = 10 MILLION CYCLES FOR FERROUS ALLOY PARTS
= 30 MILLION CYCLES FOR NON-FEROUS ALLOY PARTS

## COMPONENT/SUBSYSTEM TESTING

| TEST PERFORMED | SSME | F-1 | J-2 | JET | RL-10 | LR87 | LR91 |
|---|---|---|---|---|---|---|---|
| COMPONENT STRUCTURAL TESTS | (1) | (1) | | (1) | (2) | (2) | (2) |
| COMPONENT DYNAMIC TESTS | X | X | X | X | NI | X | X |
| COMPONENT DURABILITY TESTS | (2) | | | X | X | NI | NI |
| COMPONENT PROOF PRESSURE TESTS | X | (2) | (2) | X | X | X | X |
| COMPONENT SPIN TESTS | (2) | | | X | | | |
| COMPONENT TESTING DURING DEVELOPMENT | X | X | X | X | X | X | X |
| SUBSYSTEM OPERATIONAL VERIFICATION | X | X | X | X | X | X | X |
| SUBSYSTEM TESTING DURING DEVELOPMENT | X | X | X | X | X | X | X |

NOTE: (1) ALL MAJOR COMPONENTS
(2) CRITICAL COMPONENTS
NI = NO INFORMATION

## SYSTEM LEVEL DEVELOPMENT TESTS

| TEST PERFORMED | SSME | F-1 | J-2 | JET | RL-10 | LR87 | LR91 |
|---|---|---|---|---|---|---|---|
| SYSTEM LEVEL DYNAMIC TESTS | | X | X | X | X | X | X |
| SYSTEM LEVEL DURABILITY TESTS | X | X | X | X | X | X | X |
| SYSTEM LEVEL THERMAL TESTS | (4) | X | X | X | | X | X |
| SYSTEM LEVEL OPERATIONAL VERIFICATION | X | X | X | X | X | X | X |
| SYSTEM LEVEL MARGIN TESTS | X | X | X | X | X | X | X |
| OTHER SYSTEM LEVEL TESTS | | (3) | | (1) | | (2) | (2) |
| SYSTEM LEVEL TESTING PRIOR TO FLIGHT | X | X | X | X | X | X | X |

NOTE: (1) CAPABILITY OF ENGINE TO INJEST OBJECTS AND TO CONTAIN FAILURES ARE ALSO VERIFIED
(2) ENGINE STORAGE CAPABILITY IS EVALUATED
(3) THERMAL PROTECTION SYSTEM THERMAL TEST
(4) PART OF VEHICLE SYSTEM TESTS

# CERTIFICATION/QUALIFICATION TESTS

| TEST ATTRIBUTE | SSME | F-1 | J-2 | JET | RL-10 | LR87 | LR91 |
|---|---|---|---|---|---|---|---|
| NUMBER OF TESTS REQUIRED | 10 | 20 | 30 | N/A | 20 | 12 | 12 |
| TOTAL TEST DURATION REQ. | 5000 S | 2250 S | 3750 S | 150 H | 4500 S | 1992 S | 2532 S |
| NUMBER OF SAMPLES | 2 | 1 | 2 | 1 | 3 | 1 | 1 |
| HARDWARE CHANGES ALLOWED | YES | YES | YES | YES | NO | YES | YES |
| FLEETLEADER CONCEPT USED | YES | NO | NO | YES | NO | NO | NO |
| OVERSTRESS TESTING | YES | NO | NO | NO | YES | NO | NO |

## OBSERVATIONS

- **ROCKET ENGINE AND DEVELOPMENT AND CERTIFICATION PROCESS IS "DESIGN-TEST-FAIL-FIX" UNTIL SYSTEM IS CONSIDERED MATURE ENOUGH TO FLY**
- **FORMAL CERTIFICATION TEST PROGRAMS ARE AIMED AT DEMONSTRATING DESIGN MATURITY AND OPERATIONAL READINESS**
- **CONFIDENCE TO FLY IS GAINED THROUGH:**
  - APPLICATION OF HEURISTIC RULES
  - HISTORICALLY BASED FACTORS OF SAFETY IN DESIGN
  - ACCEPTED DESIGN PRACTICES
  - DEVELOPMENT TEST OF COMPONENTS, SUBSYSTEMS AND SYSTEM (NOT REQUIRED TO BE FINAL FLIGHT DESIGN)
  - AS WELL AS FINAL FLIGHT DESIGN IN CERTIFICATION TEST SERIES
- **CERTIFICATION TEST SERIES TYPICALLY SUPPORTS A DEMONSTRATED RELIABILITY ON THE ORDER OF 70 TO 80% (AT LOW CONFIDENCE) FOR FLIGHT USE**

## WORKING LIST OF IDEAL CHARACTERISTICS FOR SPACE BASING (PRELIMINARY)

- NO LEAKAGE ALLOWED
- NO ENGINE PURGES
- NO ENGINE PRECONDITIONING
- NO EXTERNAL FLUIDS OTHER THAN PROPELLANTS
- NO MATERIAL DEGRADATION DUE TO SPACE EXPOSURE
- NO "HANDS-ON" INSPECTION OF THE HARDWARE PRE/POST FIRING
- VERIFIABLE HEALTH MONITORING CAPABILITY AND RESPONSE
- REMOVABLE AND MAINTAINABLE AT SOME LEVEL ON-ORBIT
- HIGH RELIABILITY
- NO SCHEDULED MAINTENANCE
- RECONFIGURATION STRATEGY DURING FIRING IF NECESSARY

## CHALLENGE: WHAT WILL BE REQUIRED TO CERTIFY A REUSABLE, SPACE-BASED ENGINE AND PROPULSION SYSTEM FOR FLIGHT USE?



- ESTABLISH A METHODOLOGY WHICH
  - DEFINES JUSTIFIABLE REQUIREMENTS
  - QUANTIFIES ENGINE RELIABILITY
  - MINIMIZES REQUIRED TESTING
- VERIFY THE METHODOLOGY BY EXPERIMENT
- ESTABLISH REQUIRMENTS FOR SPACE BASE ENGINE CERTIFICATION
- APPLY THE METHODOLOGY TO ENGINES FOR SEI

## PROPOSED ACTIONS/PROGRAMS

- PERFORM A SURVEY OF METHODS, TOOLS, AND DATA APPLICABLE TO CERTIFICATION
- DEFINE A NEW METHODOLOGY FOR CERTIFICATION
- DEVELOP TOOLS TO SUPPORT METHODOLOGY
- VERIFY TOOLS AND METHODOLOGY BY TEST
- DEFINE REQUIREMENTS FOR SPACE BASED CERTIFICATION



- JET PROPULSION LABORATORY CERTIFICATION METHODOLOGY STUDIES
- LEWIS RESEARCH CENTER CERTIFICATION METHODOLOGY DEVELOPMENT
- SAE - G11 RC LIQUID ROCKET ENGINE CERTIFICATION SUBCOMMITTEE OF THE RELIABILITY, MAINTAINABILITY, AND SUPPORTABILITY COMMITTEE