Ability to Tolerate Credible System Failures

Space Propulsion Technology
Assessment Workshop

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Current Baseline
Ability to Tolerate Credible System Failures

- Rocket engines have about ten times the power density of jet engines

- Large amounts of energy in a system failure
  - Kinetic energy (e.g., turbine blade failure)
  - Large amounts of high pressure, hot gases
    - Rapid and very large expansion if ruptured

- Currently no quick shutdown
  - Gas and energy supply continues

- Result
  - Failure of component will probably destroy entire engine
  - Will possibly destroy all the engines in a cluster
  - Will possibly destroy entire vehicle

Potential Approach
Ability to Tolerate Credible System Failures

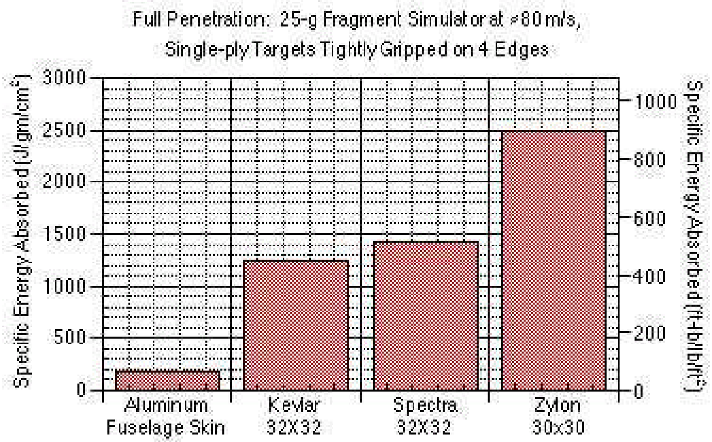
- Tolerating system failure requires
  - Containment of rotating machinery failures
  - Hot and cold gas management after pressure vessel rupture
  - Collateral damage to other subsystems/engines/vehicle
  - Safe shutdown after failure

- This must be done within the context of
  - Engines are typically clustered or internal to vehicle
  - Impact ignition and subsequent fire in high pressure oxygen systems must be managed

- The best possible failure tolerance approach is to detect incipient failure and shutdown engine before problem occurs
  - Very good, predictive engine health management
  - The harder this approach is pushed, the higher false alarm rate that must be tolerated

Technologies to Implement Solutions (TRLs)
Ability to Tolerate Credible System Failures

- Engine
  - Engines isolated from each other with barriers and blowout vents in vehicle (4)
  - Locate turbomachinery in critically controlled area of engine/vehicle (isolate/shroud), oriented away from critical subsystems within the vehicle (4)



- Turbomachinery
  - Housings designed to contain single blade failure without rupture (3)
  - Ballistic Kevlar or Zylon wrapped housings for additional shrapnel containment (3)

Technologies to Implement Solutions (TRLs) (Cont'd)
Ability to Tolerate Credible System Failures

- Gas Management
  - Shroud high risk components (3)
  - Contain and direct, or deflect gas out of vehicle (4)
  - Design for leak before burst (3)
  - Double wall combustion chamber construction to direct hot gas away from critical subsystems without burn through (3)
    - Short duration event

- Impact ignition and fire (pressure vessel rupture)
  - Only burn resistant materials used in oxygen system (5)
    - Prevent fire from starting
  - Oxygen depleting fire suppression system (3)

- Other components
  - Kevlar or Zylon shrouding (3)
  - Shaped shrouds for deflecting (3)

- Materials
  - Materials that shatter instead of tear (some ceramics) (2)
  - Materials that break into parts on failure (2)
  - Failure in selected directions (2)

- System
  - Quickest possible shutdown after failure (3)

Observations
Ability to Tolerate Credible System Failures

- It is highly important that system is shut down as quickly as possible after failure
    - Minimize energy to be dissipated
- Successful failure tolerance requires high level of vehicle/engine integration
- Multi-layered approach required to address multiple failure possibilities
- Significant trades required
    - Containment, reliability, weight, performance, cost, complexity
- Approaches are speculative and immature
- Failure tolerance verification, beyond analysis only, will be expensive
    - Significant engine and test stand risk in verification tests
- Highest price may not be cost
    - Weight penalties for most approaches will be very large
        - Weight could double

Cost to Mature Technology

Ability to Tolerate Credible System Failures