# VULCAN

## Industry Day Agenda
## June 10, 2008

**8:00-8:30** **Registration open**

**8:30-9:00** **Welcome – Dr. Tom Bussing (and Steve Welby)**

- Agenda Rvw/Today's intent
- DARPA/TTO's Charter…..

**9:00-9:30** **Hypersonic Vehicle Challenges (Dr. Steve Walker)**

**9:30-10:30** **VULCAN Overview (Dr. Tom Bussing)**

- Program Vision
- Objectives / Goals

**10:30-10:45** **Break/Network**

**10:45-11:15** **PDE Consortium (Dr. Joe Doychak presented by Fred Schauer)**

**11:15-11:45** **AFRL Technology Brief (Dr. Fred Schauer)**

**11:45–12:15** **Catered Lunch**

**12:15-12:45** **Questions & Answer Session**

**12:45-1:15** **NAVY PDE Technology (Dr. Chris Brophy)**

**1:15-1:45** **NASA PDE Technology (Dr. Dan Paxson)**

**1:45-2:00** **Break/Network**

**2:00-2:20** **Acquisition Strategy (Dr. Tom Bussing)**

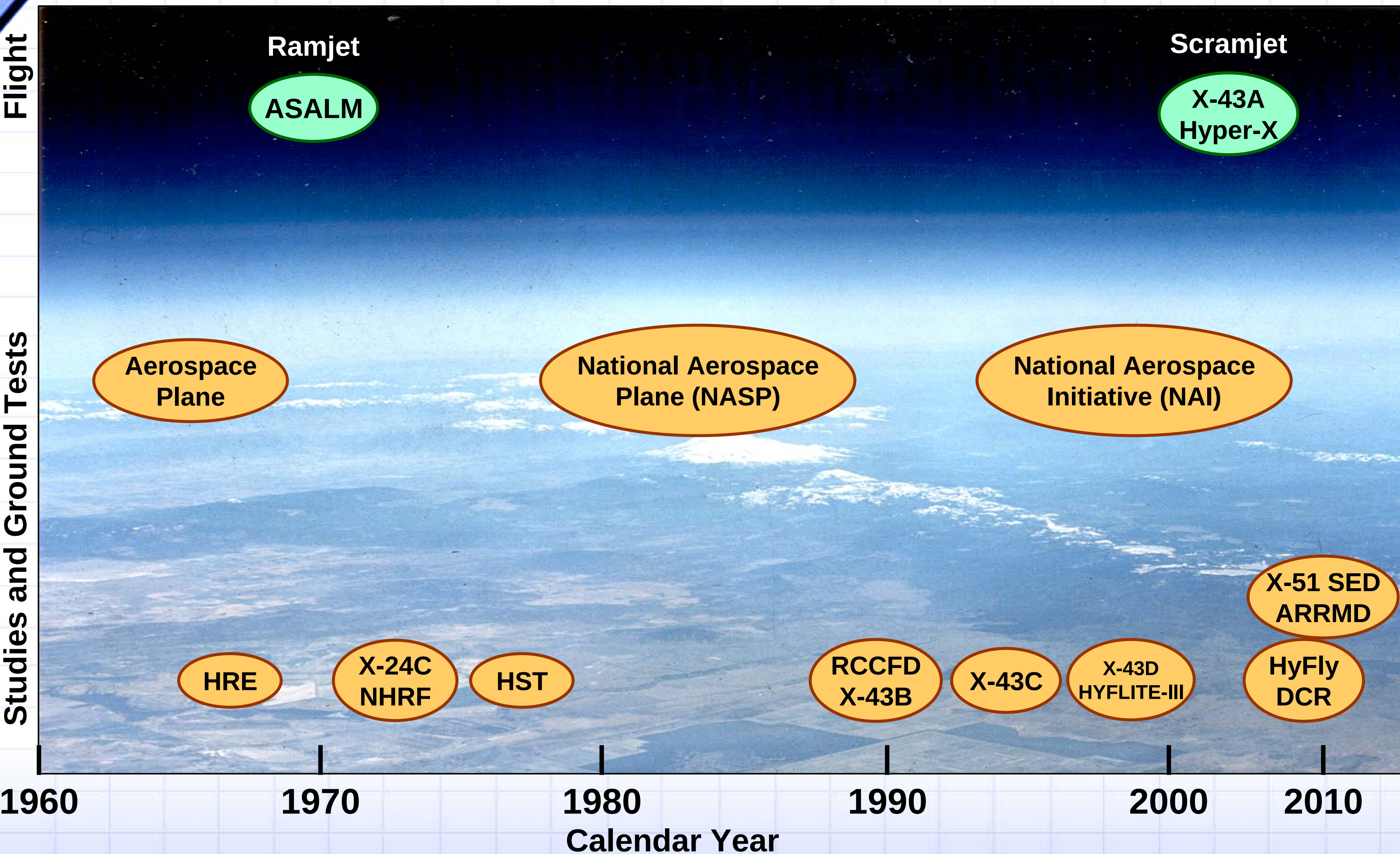
- Program Plan, outputs, schedule & events
- Near term program events (source selection schedule)

**2:20-2:40** **BAA Description / Proposal Overview (Stephen Davis/DARPA/CMO)**

**2:40-2:50** **DARPA Security (David Selby/DARPA/TTO)**

**3:00-6:00** **Side Bar Meetings with Tom @ 30 minutes each**

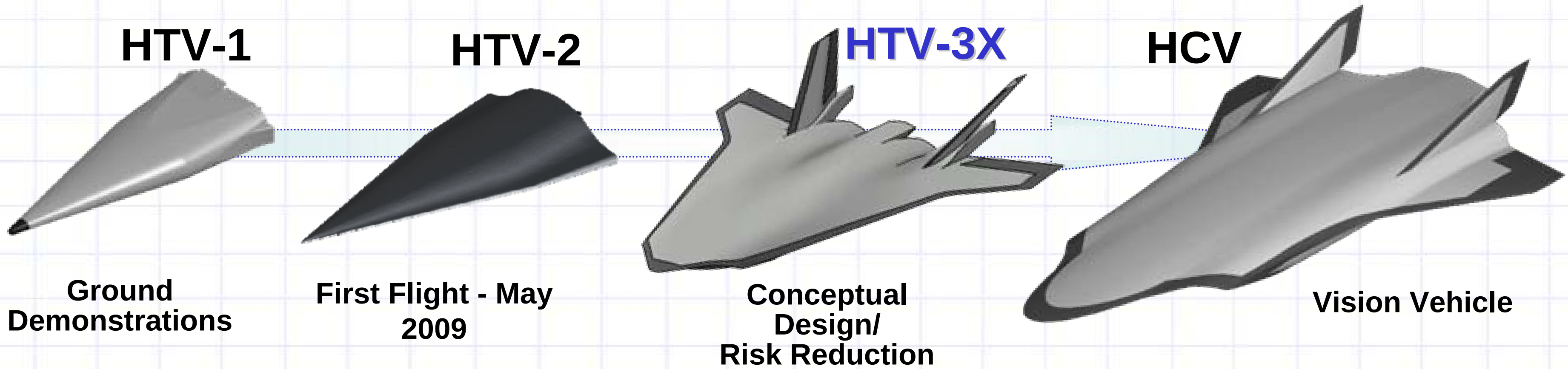
# Air-Breathing Hypersonics Historical Perspective



# Falcon - Hypersonics

## Program Goals and Objectives

Demonstrate key Hypersonic Cruise Vehicle Technologies in-flight through a series of Hypersonic Technology Vehicles (HTVs)




## Technical Approach

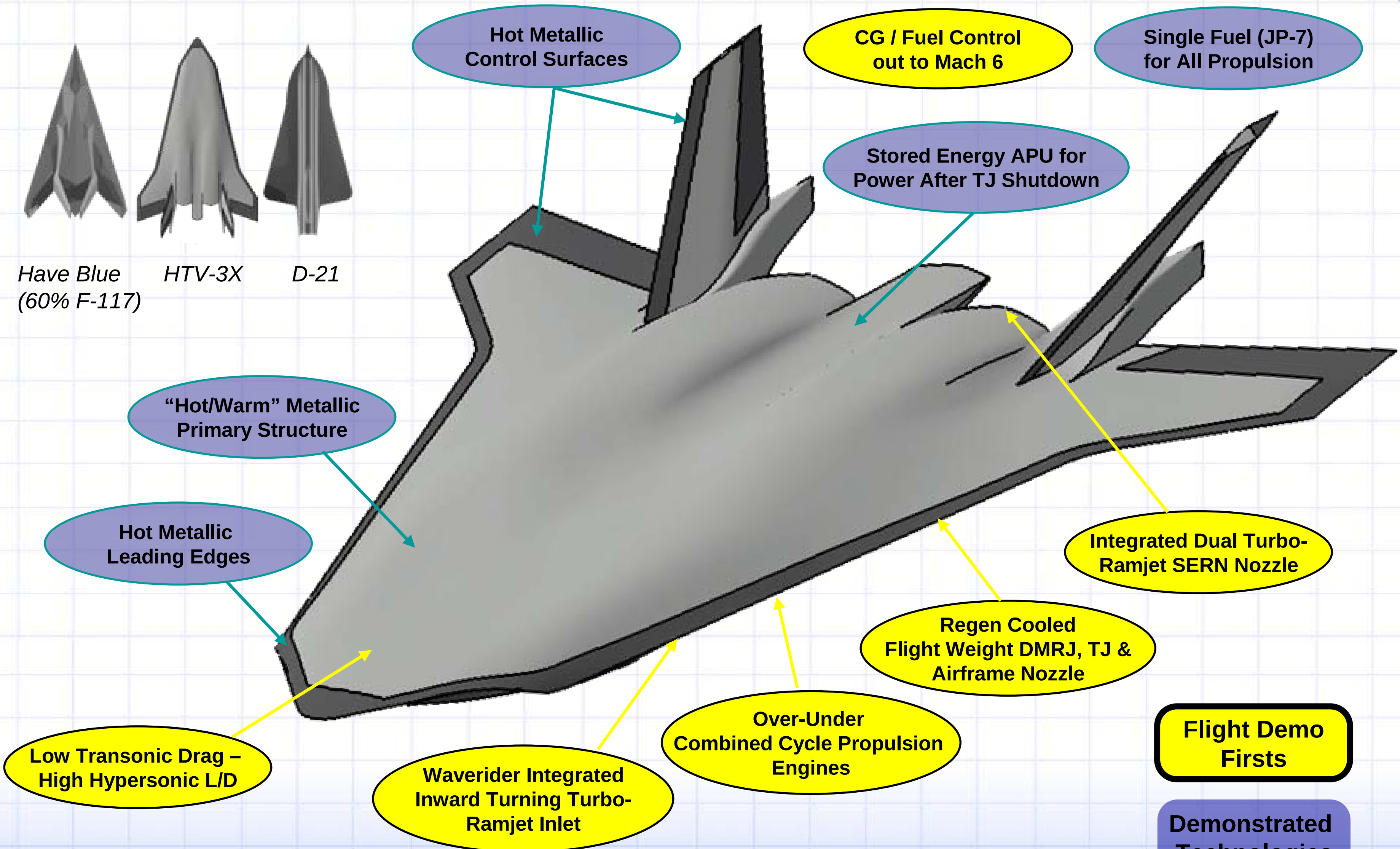
- Aero-Thermal Dynamics
- High-Temperature Materials & Structures
- Navigation Guidance and Control
- Communications through Plasma
- Combined Cycle Propulsion

## Military Utility

- Prompt Global Reach from CONUS
  - Reconnaissance
  - Anti-access capability
- Reusable Space Access
  - Aircraft-like operations

***Demonstrating Long-Duration Hypersonic Flight***

# Falcon HTV-3X
## Flight Demonstration Vehicle



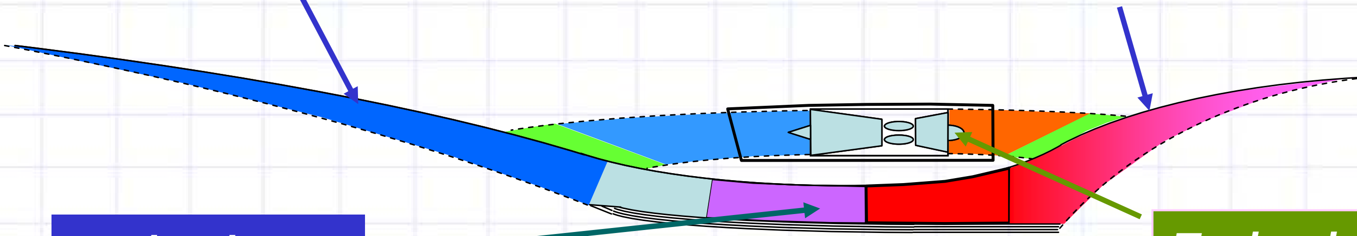
# Turbine-Based Combined Cycle Technology Challenges

*Technology 1*

**Common Inlet System**
- Inlet Starting (Turbojet through DMRJ Transition)
- Inlet Performance / Operability

*Technology 3*

**Common Nozzle System**
- Turbojet Effluent Integration



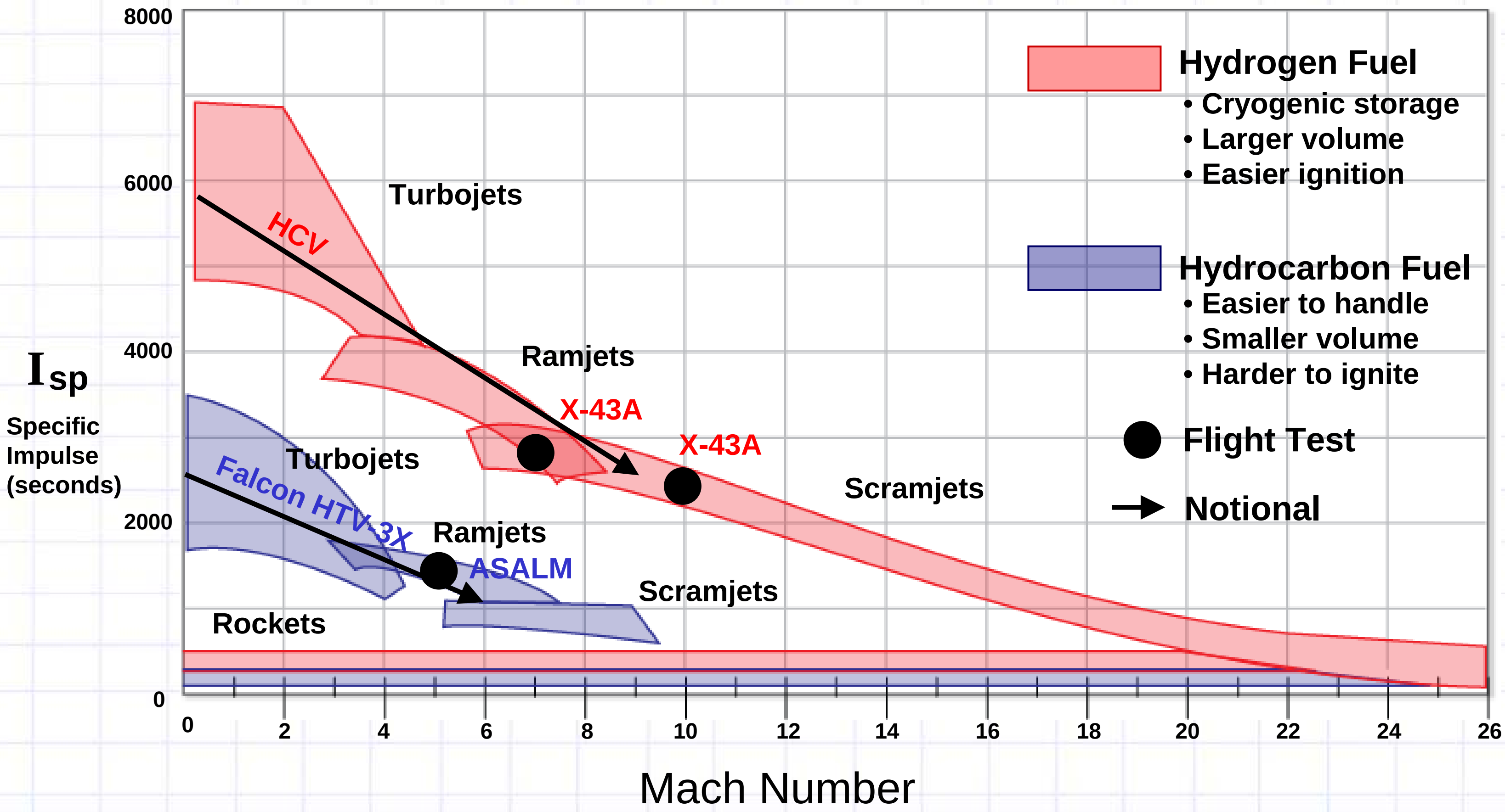
*Technology 2*

*Technology 4*

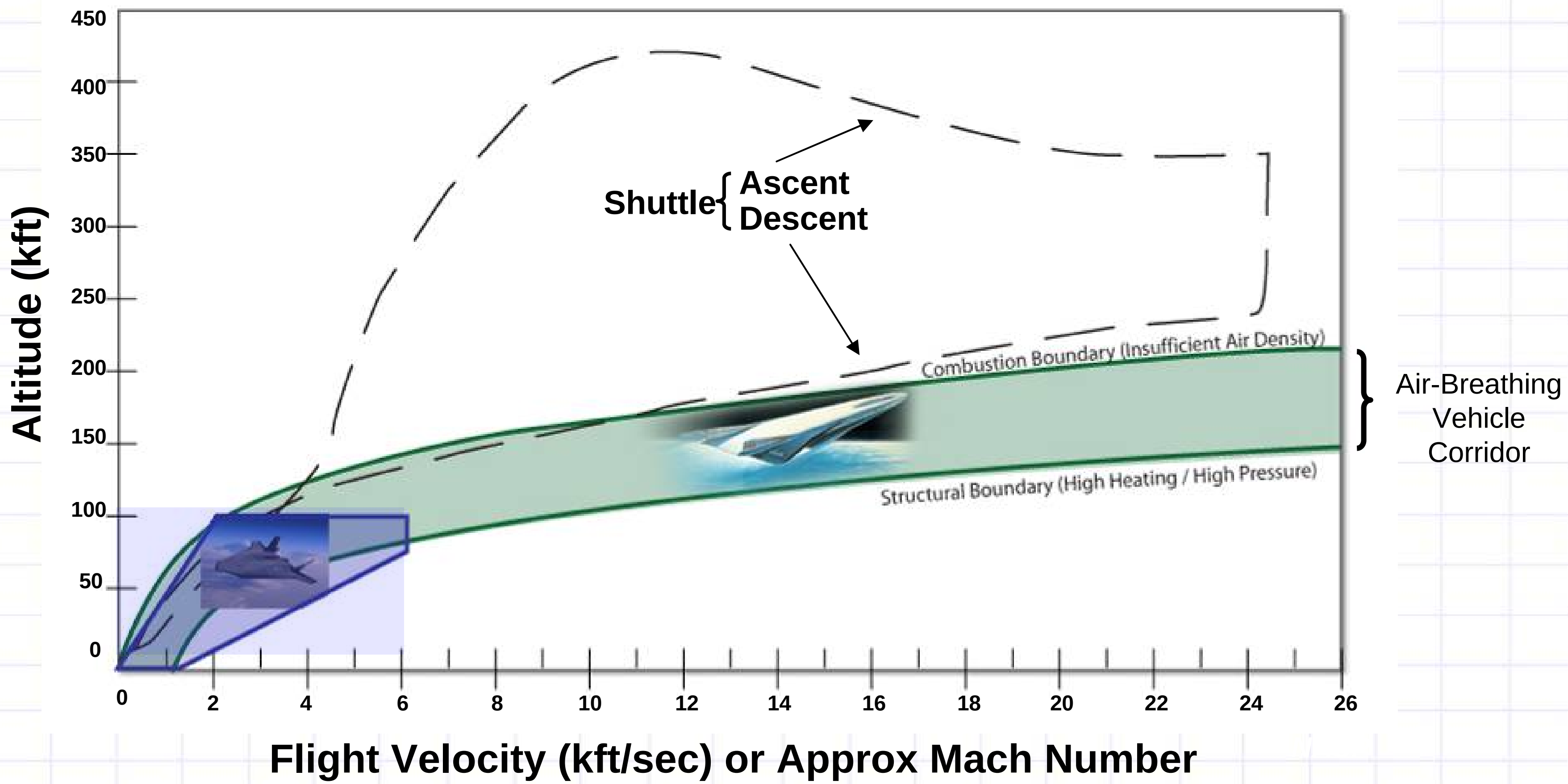
**Dual Mode Ramjet Combustor (DMRJ)**
- Combustion Performance
- Combustor Operability (Low Q Flight)
- Structural Concept
- Flt Weight, Efficient Structural Concept

**Mach 4 Turbine Engine**
- Thrust per unit frontal area (lbf/ft2)
- High Turbine Entrance Temp
- High Temperature Bearings
- High Mach Thermal Mgmt
- Installation Effects
- Scaling; Reusability & Life
- Hot Shutdown / Cocooning / Restart

# Air-Breathing Hypersonics
## Flight Tests to Date



# Falcon HTV-3X
## DARPA- Hard, But not NASP



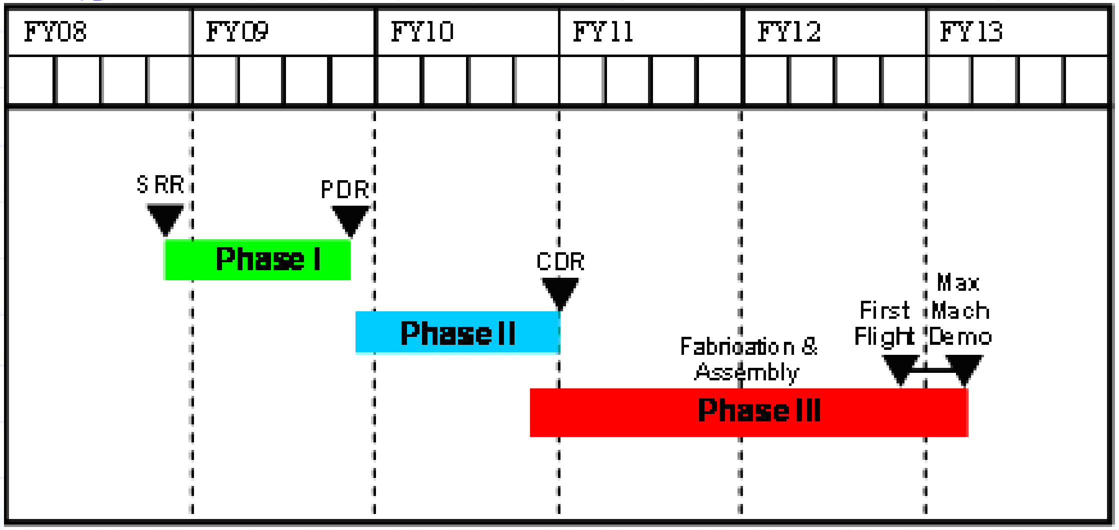
# Blackswift Hypersonic Testbed
# Solicitation Schedule & Program Plan

## Solicitation Schedule:

**DARPA requests contract proposals to design, build, and fly Mach 6+ re-usable, air-breathing hypersonic, turbine-based combined-cycle hydrocarbon-fuel demo aircraft**

- March 3, 2008 – solicitation release to Federal Business Opportunities
- May 19, 2008 – proposals due
- 4Q FY08 – contract award and announcement

## Program Plan:




SRR – Systems Requirements Review
PDR – Preliminary Design Review
CDR – Critical Design Review

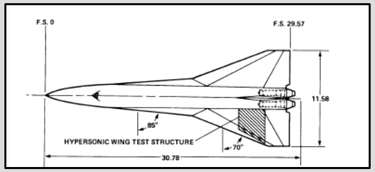
***Aggressive schedule and cost goals demand OTS High Mach Turbine***

# March Toward Hypersonic Capability

## Blackswift Bridges the Gap

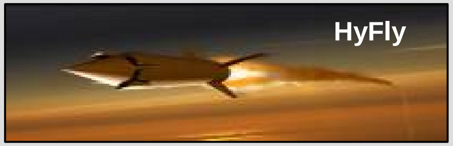
TECHNOLOGY READINESS — UTILITY

1960 → 2007

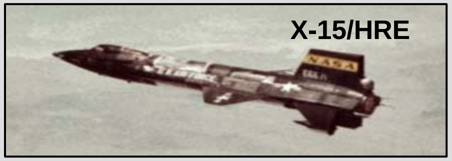



HWTS Hot Structure

HRE-SCRAMJET

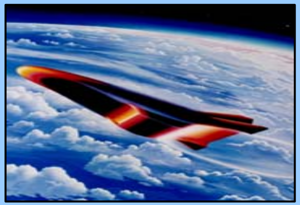









**Fully Integrated system**



**Hypersonic Atmospheric Flight and Access to Space**

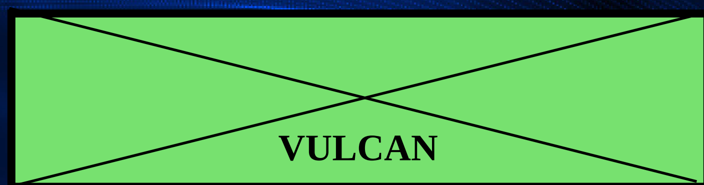
**+ Vulcan**

| Analysis & Ground Test | Flight Test – Air Launch – Rocket Boost | Powered T/O, Flight, & Land | Operational Capability |
|---|---|---|---|

# Introduction

# The VULCAN Engine Demonstration Program

# Industry Day Briefing




Full Scale Hypersonic Vehicle **ENABLER**

**Thomas Bussing**
**DARPA/TTO**
**thomas.bussing@darpa.mil**
**(571) 218-4212**

***Presented to:***
***Industry Performers***
***June 10, 2008***

# VULCAN Engine Program Objective

**VULCAN is a propulsion system demonstration program to design, build and ground test an engine capable of accelerating a full scale hypersonic vehicle from rest to Mach 4+. The VULCAN engine will consist of an integrated Constant Volume Combustion (CVC) engine and a full scale turbine engine. CVC engine architectures, could include Pulsed Detonation Engines (PDE's), Continuous Detonation Engines (CDE's) or other unsteady CVC engine architectures. The CVC engine would operate from below the upper Mach limit of the turbine engine to Mach 4+. The turbine engine will be a current production engine capable of operating above Mach 2 and may be based on any of the following engines, the F100-229, F110-129, F119 or F414 engines. A key objective of the program is to integrate the turbine engine into the VULCAN engine with minimal modification to the turbine engine, to operate the turbine engine from rest to its upper Mach limit and to cocoon the turbine engine when it is not in use. It desired that both the turbine and the CVC engines share a common inlet and nozzle. It is envisioned that developing the VULCAN engine will enable full scale hypersonic cruise vehicles for intelligence, surveillance, reconnaissance, strike or other critical national missions.**

# What VULCAN Is

1. A Mach 0 to 4+ engine design, development and demonstration program
2. An unsteady Constant Volume Combustion (CVC) design, development and demonstration program
3. A full scale turbine and CVC integration program
4. A full scale turbine/CVC engine demonstration program at representative Mach and altitude conditions

# What VULCAN Is Not

1. A high Mach turbine engine development program - DARPA’s goal is to develop a high Mach engine around a production Mach 2+ turbine
2. A VULCAN/Scramjet engine development program, only Mach 0-4+

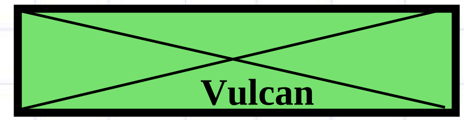
# History

# High Mach Engine Development

# High Mach Full Scale Airbreathing Engine Development History

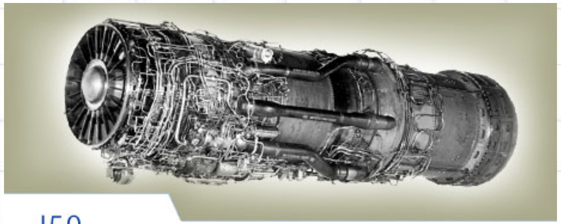
| | Goal/Advantages | Issues |
|---|---|---|
| **TJ/CVC (Vulcan)** | -Mach 4+<br>-Use production turbine engine "unmodified"<br>-Development cost small fraction of all new turbine<br>-CVC 20-30% higher average SFC than ramjet<br>-CVC's can operate from Mach 0-4+ | -CVC development<br>-TJ/CVC mode transition<br>-Cocooning turbine |
| **RTA**<br>NASA Program stopped in 2005<br>Low level funding under ADVENT | -Mach 4+<br>-Develop all new high Mach turbine/ramjet engine | -All new turbo machinery, high development cost<br>-TMS, seals, lubrication remain challenges<br>-Cocooning turbine |
| **J58**<br>Powered SR-71 | -Mach 3.2 | |

Future




TJ/CVC

RTA



J58

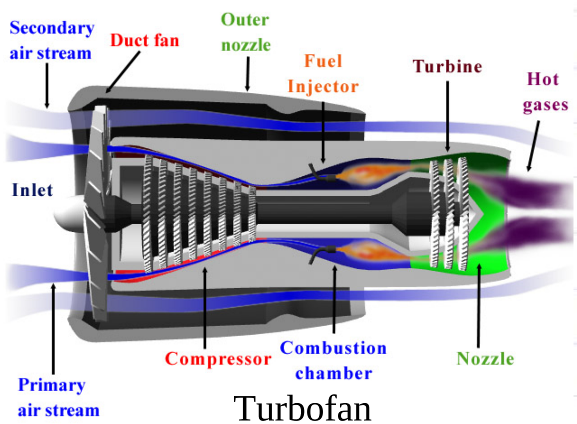
Past

**TJ/CVC engine designed to meet full scale hypersonic vehicle need**

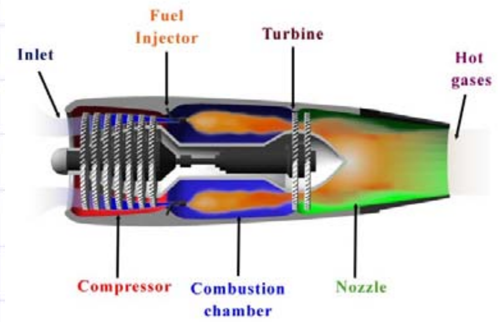
# CVC Background

# Current State of the Art in Aviation Propulsion and Power Generation – The Brayton Cycle

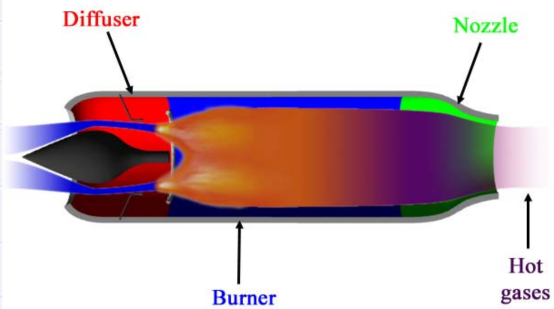
## Conventional aviation engines




Turbofan

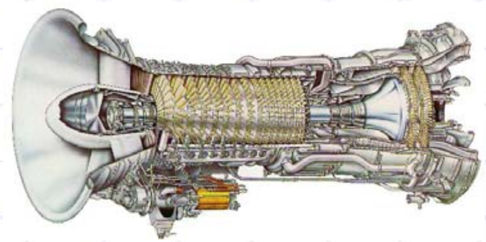



Turbojet




Ramjet

## Conventional power generation engines

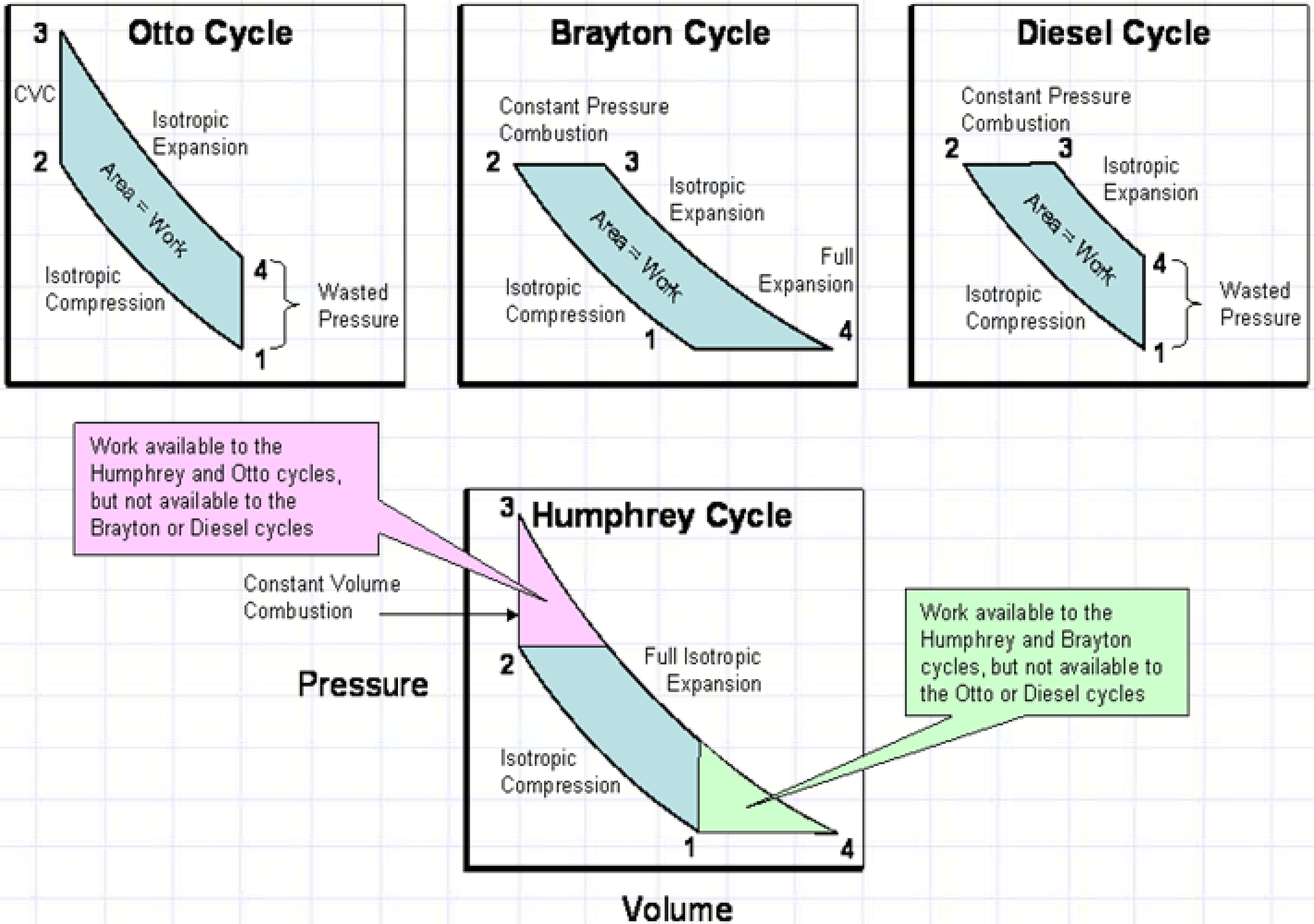


Ground Based Power Turbine

Ground Based Power Diesel

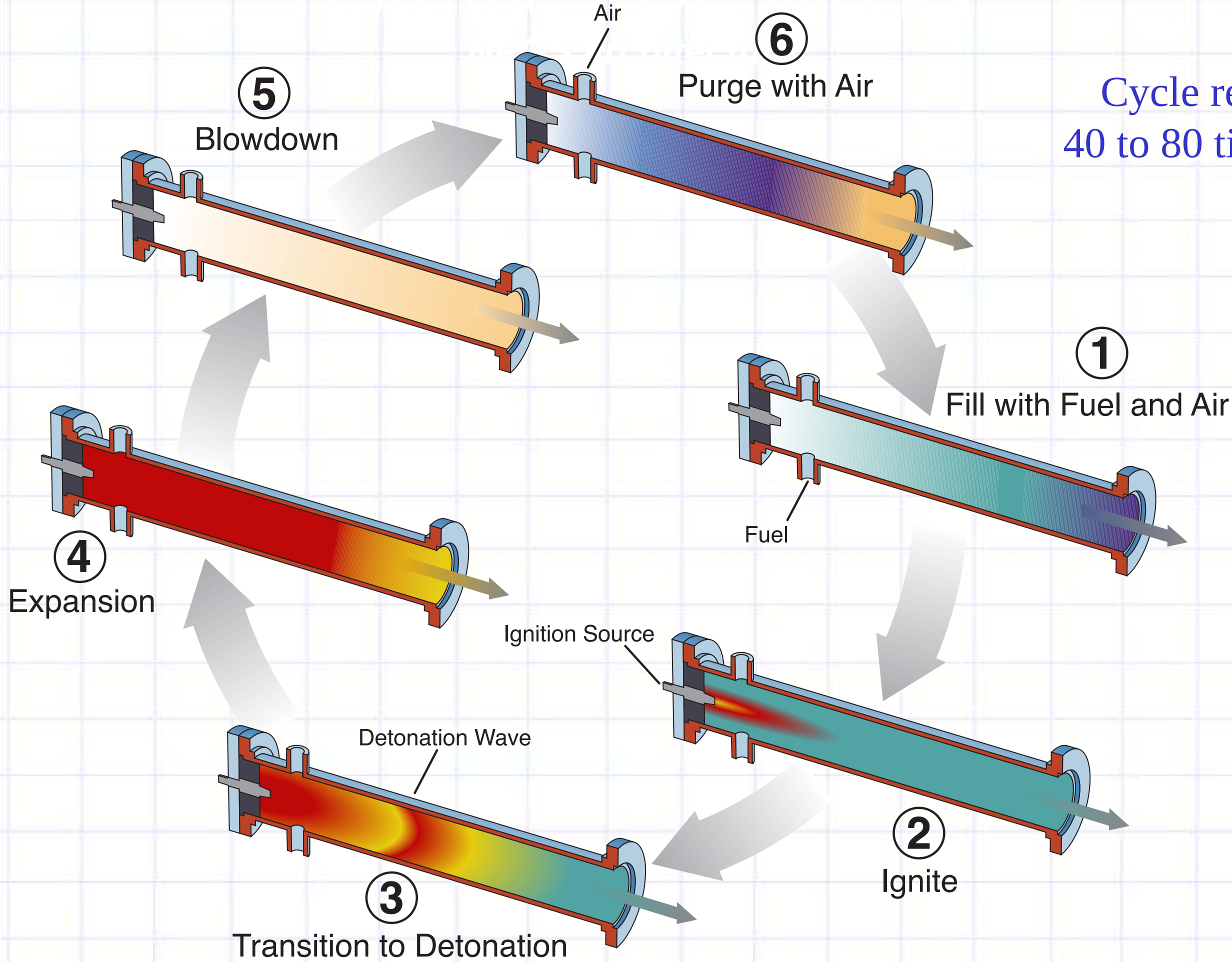
**All conventional aviation and ground based power generation engines are based on constant pressure combustion i.e. the Brayton Cycle**

# How Can We Do Better Than A Brayton Cycle?
# Answer – The Humphrey Cycle




**Humphrey (CVC) Cycle offers significant performance improvement over the Brayton Cycle A game changer!**

# Basic Operation Of The Classical PDE Cycle



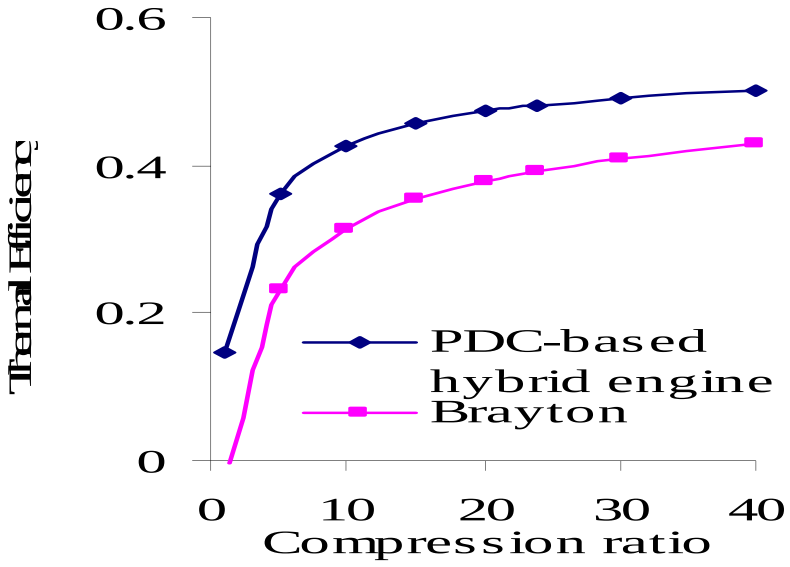

Cycle repeated up to 40 to 80 times per second

**Simple basic cycle, implementation technically very challenging**

# Thermal Efficiency Comparison
# Humphrey vs. Brayton

**State of the art:** Current R&D efforts focused on Brayton Cycle improvements, only very small improvements possible

**Innovation:** A Humphrey or Pulse Detonation Constant Volume Combustor (CVC) Cycle offers a novel way to achieve game changing performance improvements



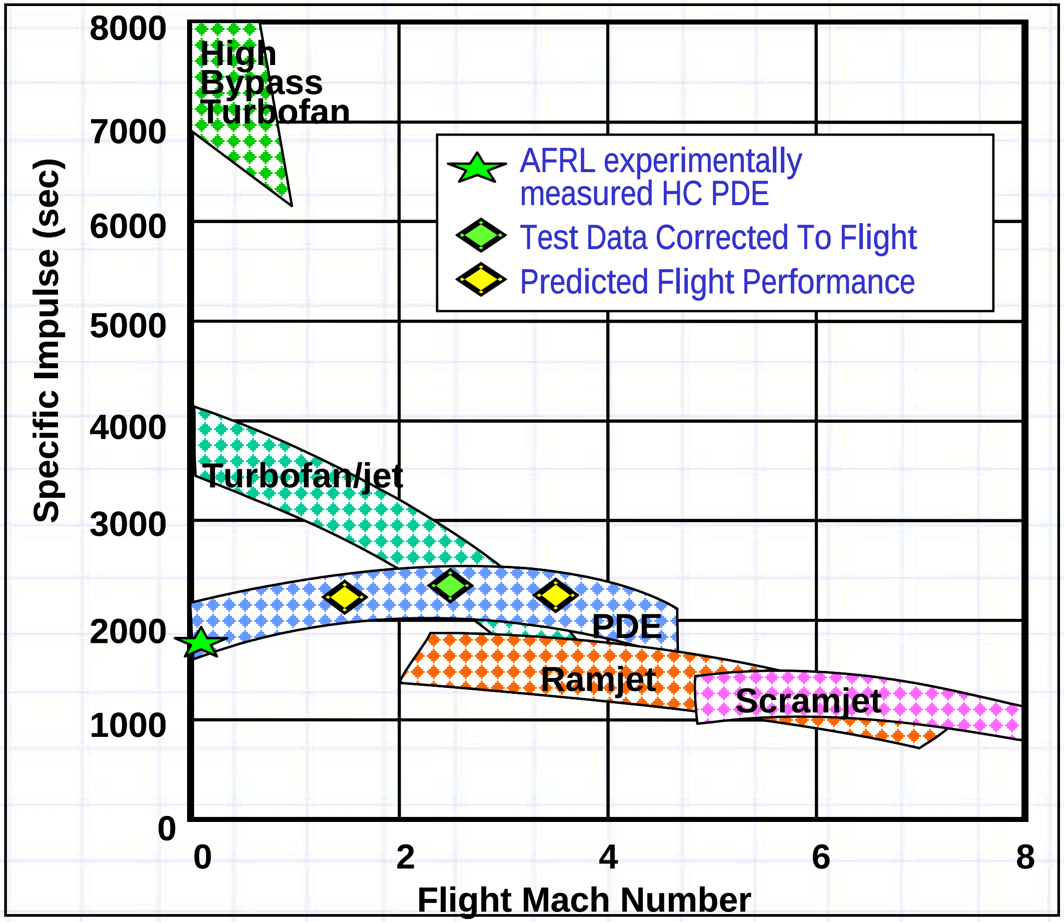

Carnot Thermal Efficiency 77%
($Eff_{TF} = 1 - T_o/T_m$)

A compression ratio of 17 is equivalent to the stagnation pressure ratio at Mach 2.5

**The ideal CVC Cycle thermal efficiency is 9-10% higher than the Brayton Cycle (CR =17), translating to an ideal SFC improvement of 30-35% - A game changer!**

**Chart may be requested from Dr Thomas Bussing by sending an email to BAA-08-53@darpa.mil**

# CVC Operation Demonstrated Over A Range Of Mach Numbers - Experimental Validation




**Experimental data indicates high speed CVC engine possible with a Significant Specific Impulse advantage over a Ramjet over the Mach Range of Interest**

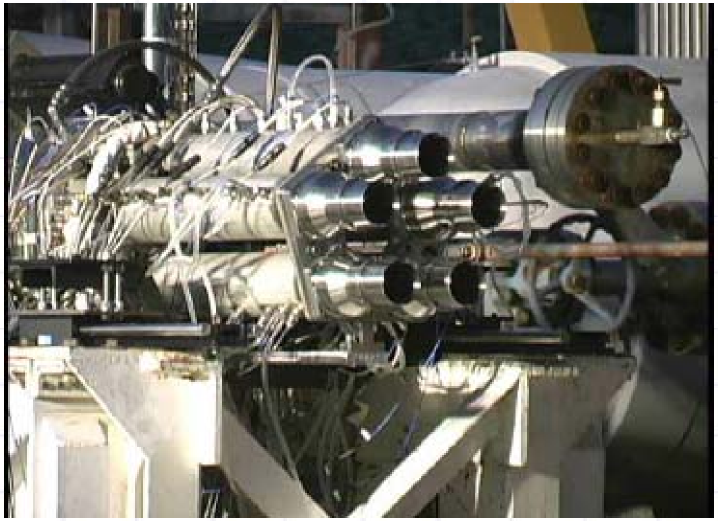
# State of the Art In CVC Development

## CVC Rig Videos

**ASI/P&W**

**AFRL**

**GE**

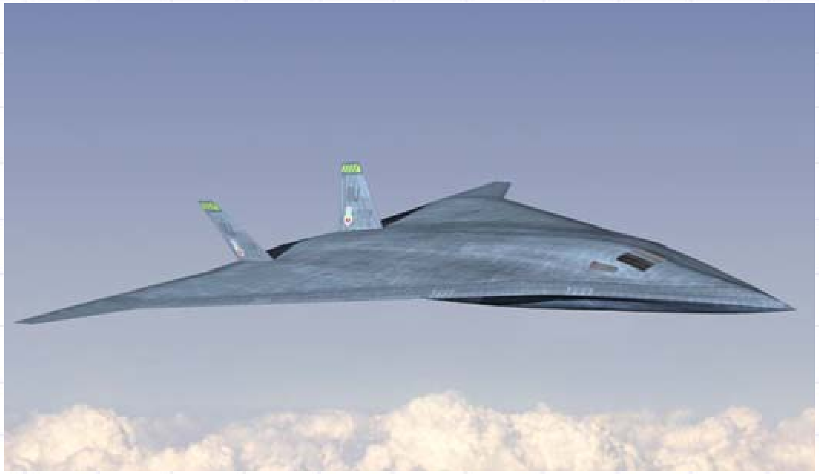


**Proof of concept rig tests have shown the promise of the PDCVC Cycle**

# High Mach TJ/CVC Based Engine Applications

# High Speed Cruise Vehicles
# Mach Number 0 – 4+

## VULCAN Engine Powered



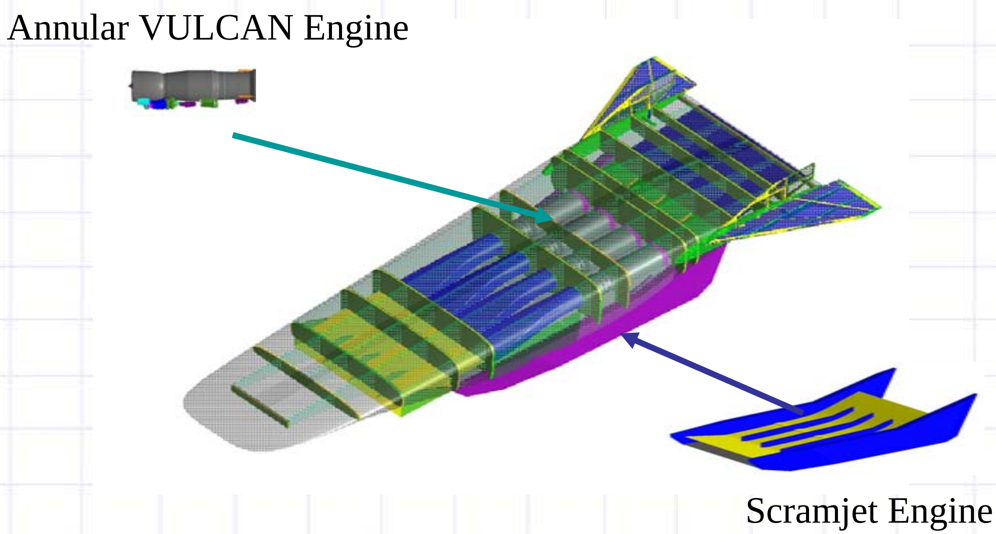
***Applications include high speed, long range reconnaissance and strike***

**Key Technology Challenges**

- **Gas Turbine and CVC operating together over Gas Turbine operating Mach range**
- **CVC only above Gas Turbine Mach number operating range**
- **Thermal Management System**
- **Light Weight/High Temperature Materials**
- **CVC Flowpath Development**
- **CVC Low Mach Technologies**
- **CVC High Mach Technologies**
- **Full Variable Geometry Actuation**
- **High Temp Dynamic/Static Seals**
- **High Temp Fuel Delivery Systems**
- **Inlet and Nozzle Flowpath Integration**

# Hypersonic Cruise Vehicles
# Mach Number 0 – 6+

## VULCAN Engine and Scramjet Engine Concept

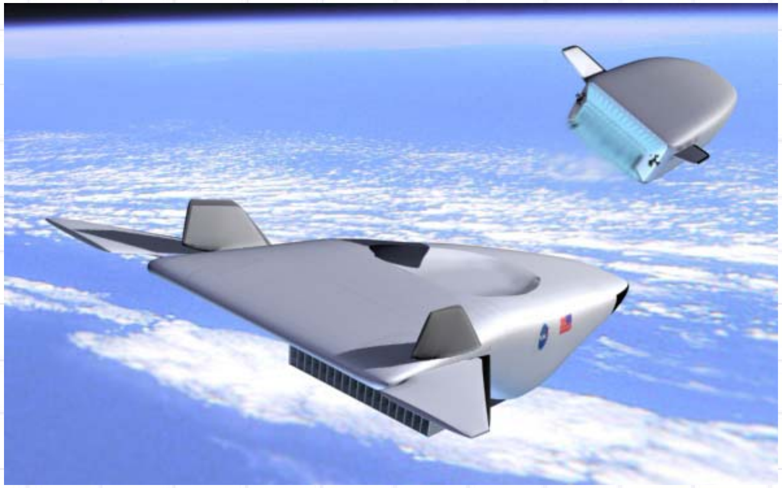



**Key Technology Challenges**

- Gas Turbine and CVC operating together over Gas Turbine operating Mach range
- Inlet mass flow matching amongst engine cycles
- CVC only above Gas Turbine Mach number operating range
- Thermal Management System
- Light Weight/High Temperature Materials
- CVC Flowpath Development
- CVC Low Mach Technologies
- CVC High Mach Technologies
- Full Variable Geometry Actuation
- High Temp Dynamic/Static Seals
- High Temp Fuel Delivery Systems
- Inlet and Nozzle Flowpath Integration

# Access to Space

## Notional VULCAN Engine and Scramjet Engine Concept



***Key technology challenges are similar to High Speed Cruise Vehicles except broader operating ranges and cryogenic fuel use must also be considered.***

**<u>Key Technology Challenges (similar to Mach 0-6 case)</u>**

- **0-6 Case Challenges**
- **VULCAN Engine to Scramjet Mode Transition**
- **Thermal Management System**
- **Light Weight/High Temperature Materials**
- **Cooled Leading Edges**
- **Scramjet Flowpath Development**
- **VULCAN Engine High Mach Technologies**
- **Full Variable Geometry Actuation**
- **High Temp Dynamic/Static Seals**
- **High Temp Fuel Delivery Systems**
- **Inlet/Nozzle Flowpath Integration**

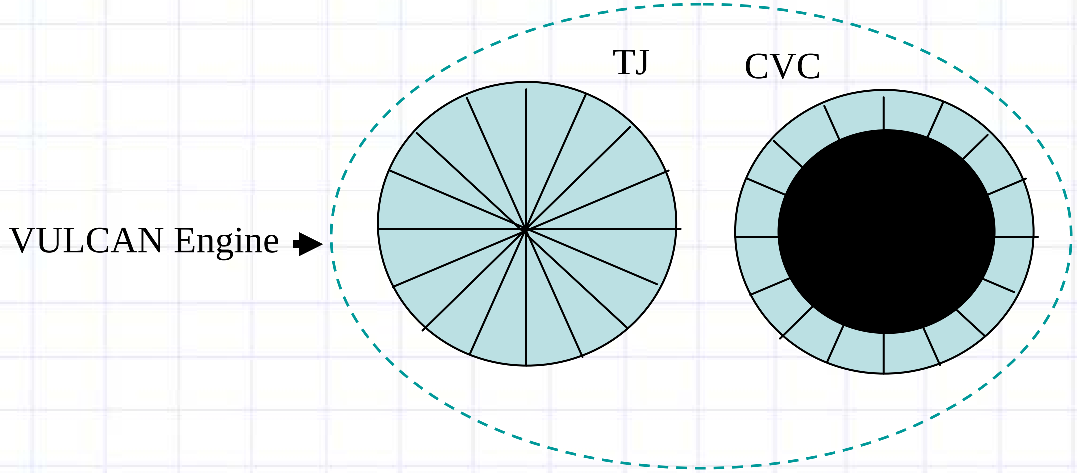
# Possible VULCAN Engine Architecture

# Possible VULCAN Transformational CVC Architectures

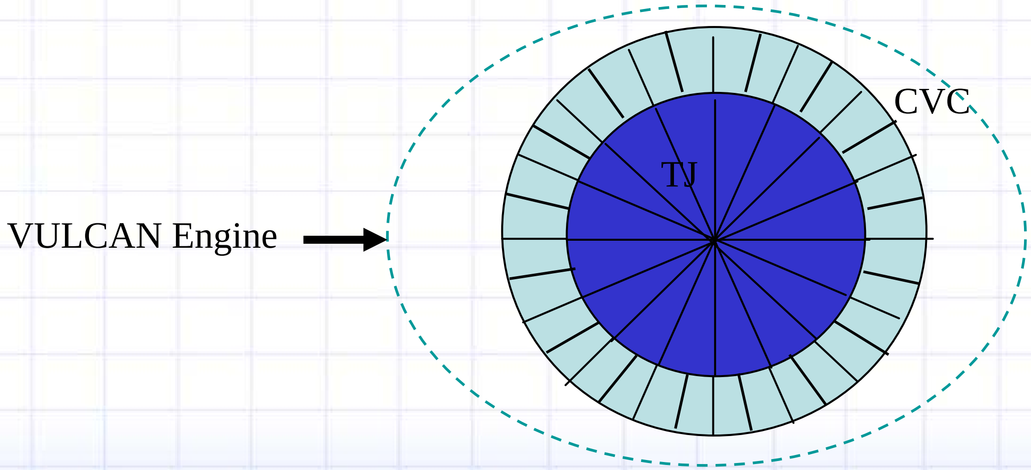
| Concept # 1 | Concept # 2 |
| --- | --- |
| Continuous Detonation Engine (CDE)<br><br>Single detonation wave propagating continuously | Pulse Detonation Engines (PDE)<br><br>Classical PDE Configurations<br>Characterized by discrete detonation events<br>Valved, unvaled, moving combustors |
| **Concept # 3**<br><br>Other Unsteady CVC<br><br>Mechanical concepts not involving detonation waves | **Concept # 4**<br><br>Other? |

**Several novel revolutionary CVC concepts identified**

# Notional VULCAN Engine Cross Section Architectures

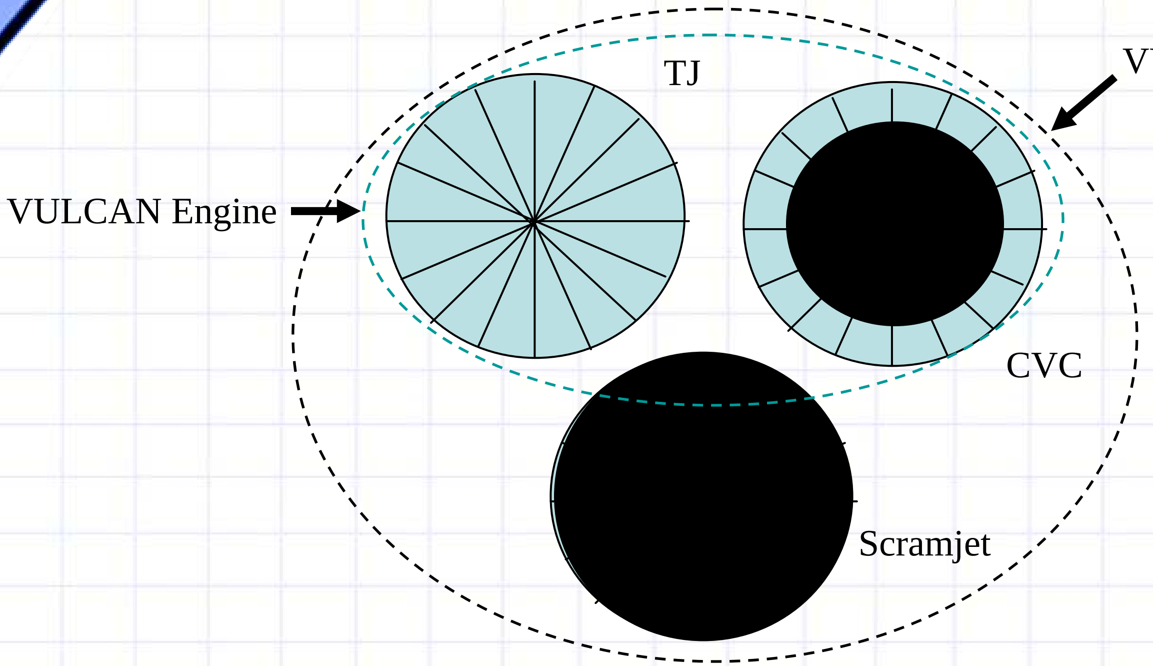



**Concept 1**
**Dual Flow Path VULCAN Engine**
**Common inlet and nozzle separate engine flow paths**



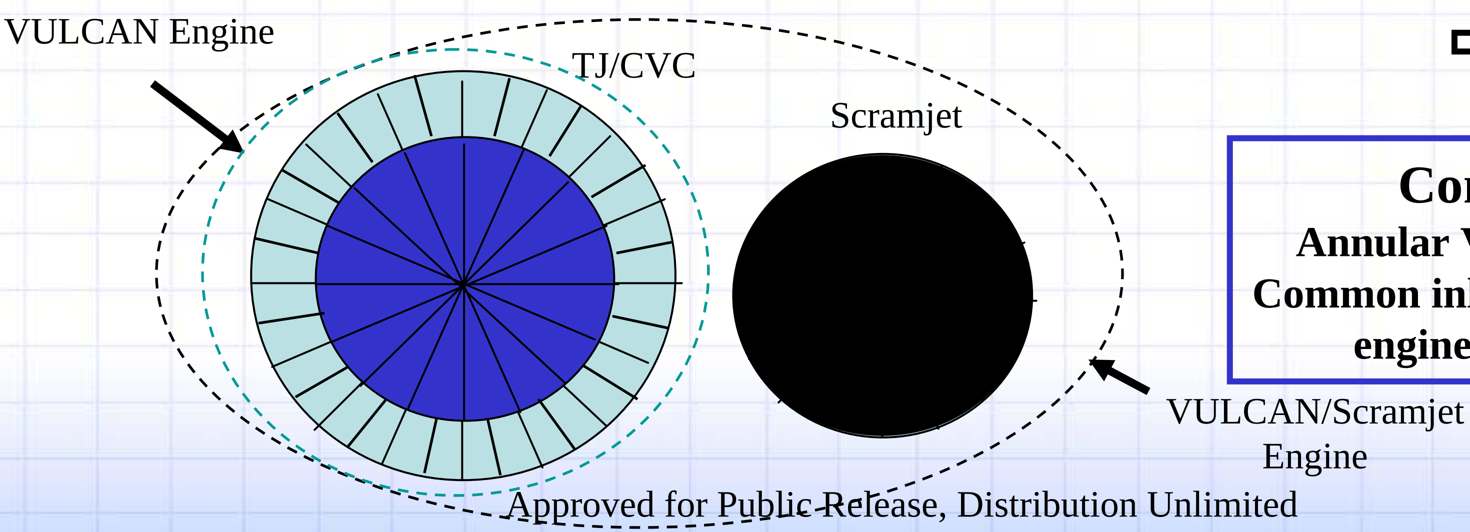

**Concept 2**
**Annular Vulcan Engine**
**Common inlet and nozzle annular engine flow paths**

# Notional Combined Cycle VULCAN/Scramjet Engine Architectures




**Concept 1**

**Dual Flow Path VULCAN Engine**
**Common inlet and nozzle - 3 separate engine flow paths**




**Concept 2**

**Annular Vulcan Engine**
**Common inlet and nozzle - 3 engine flow paths**

# Top Level VULCAN Engine Programmatics

# Full Scale Hypersonic Vehicle Engine Development Path

**Vulcan Program**

## Flight Ready Vulcan/DMRJ Engine Development Program

1) CVC Single combustor risk retirement
2) CVC Full scale valve, combustor subset risk retirement
3) CVC full scale test at representative flight conditions
4) TJ Purchase (GFE)
5) TJ Cocooning development and test
6) TJ Thermal hardening
7) TJ Nozzle re-design
8) TJ/CVC integration
9) TJ/CVC integrated inlet development and test
10) TJ/CVC Integrated nozzle development and test
11) Vulcan engine tested at representative flight conditions
12) Full scale DMRJ development and test
13) TJ/CVC/DMRJ integration
14) TJ/CVC/DMRJ integrated inlet development and test
15) TJ/CVC/DMRJ integrated nozzle development and test
16) TJ/CVC/DMRJ test at representative flight conditions

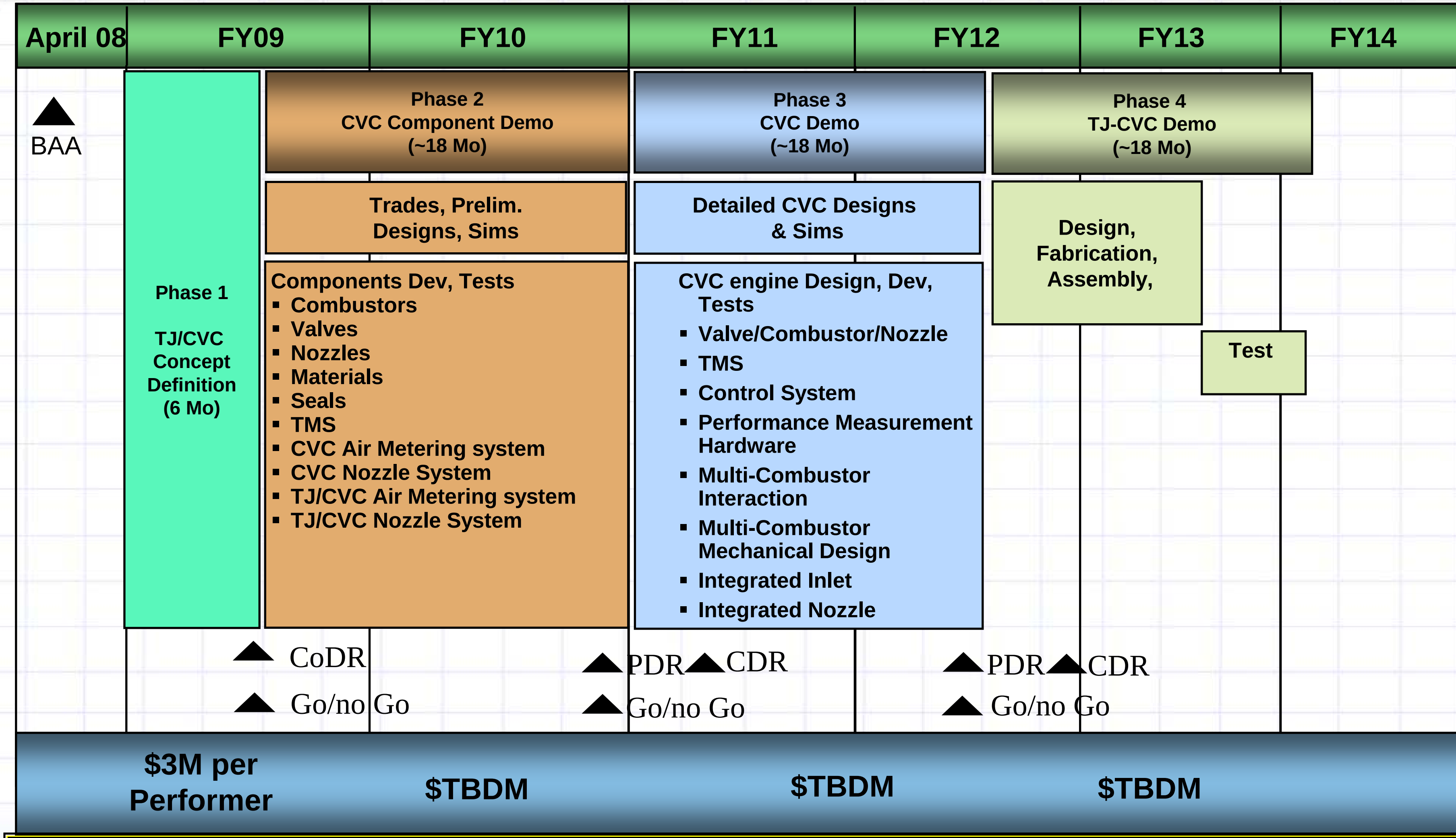
## Demonstration Vulcan Engine Development Program

1) CVC Single combustor risk retirement
2) CVC Full scale valve, combustor subset risk retirement
3) CVC full scale test at representative flight conditions
4) F119, F110-129, F100-229 or F414 Purchase
5) TJ Cocooning development

8) TJ/CVC integration
9) TJ/CVC integrated inlet required for demonstration
10) TJ/CVC Integrated nozzle required for demonstration
11) Vulcan engine tested at representative flight conditions

**Vulcan Program Focused on Key Technology Challenges**

# Notional VULCAN Engine Program Schedule and Milestones




**Program structured with clear Go/No Go criteria**

# Notional Vehicle Mach Number vs. Altitude and Mach Number vs. Uninstalled Thrust

| Mach Number | Altitude (ft)[1] |
|---|---|
| 0 | 0 |
| 1.5 | 20,530 |
| 2 | 34,000 |
| 3 | 50,490 |
| 4 | 62,540 |

| Mach Number | Turbojet Uninstalled Thrust (lb)[2,3] | CVC Uninstalled Thrust (lb) | Combined Uninstalled Thrust (lb) |
|---|---|---|---|
| 0 | 80,000 | 0 | 80,000 |
| 1.5 | 80,000 | 10,000 | 90,000 |
| 2 | 60,000 | 10,000 | 70,000 |
| 3 | cocooned | 50,000 | 50,000 |
| 4 | cocooned | 50,000 | 50,000 |

[1] Trajectory based on maintaining a Q of 1,500 lb/ft$^2$
[2] Turbojet thrust total for the vehicle
[3] Turbojet thrust will vary with turbojet lapse rate

# VULCAN Engine Programmatics

# Details in Afternoon Session

# Notional Vulcan Program Requirements

## Non-Tradable Requirements

- **Integrated turbine engine and Constant Volume Combustion (CVC) engine that must operate from 0 -- Mach 4+**
- **Full scale production turbine for the Vulcan engine as stated in the BAA with minimal modification**
- **CVC engine must be able to operate on fuel qualified for the turbine engine and must at least be capable of throttling between half and full power**
- **Integrated flow path switching inlet and nozzle design capable of:**
  - Demonstrating in three modes with continuous operation between Mach 0 to 4+: Turbine only, Turbine & CVC engine, and CVC engine only
  - Demonstrating an efficient combined inlet and nozzle architectures

## System Level Attributes

- **Propulsion system for hypersonic cruise vehicle for the following missions:**
  - Intelligence, surveillance and reconnaissance
  - Space access
  - Strike

## Tradable Goals

- **CVC engine can be Pulse Detonation Engine (PDE) or Continuous Detonation Engine (CDE) or unsteady constant volume combustion engine**
- **F100-229 , F110-129, F414 or F119 class**

# Notional Vulcan Phase I Program Plan

## Phase I – Concept Definition

- **Objectives**
  - Develop a critical technology development plan for follow on phase
  - Refine the point of departure to fulfill system requirements
  - Develop Vulcan system and flow down requirements
  - Develop engine propulsion performance model
  - Deliver a phase II proposal update
- **Programmatics/Deliverables**
  - 3rd month after award: Initial design refinement
  - 6th month after award:
    - Propulsion System Conceptual Design (CoDR)/System Requirements Review (SRR)
    - Phase II Critical Technology Development Plan
    - Engine performance model
    - Vulcan Models – 4 sets of SLA models and Vulcan conceptual operation computer animation
  - 7th month after award: Phase II technical and cost proposal update at WBS level 4
  - 8th month after award: Final Report
- **Criteria for Following Phase**
  - Feasible design that meets DARPA DIRO G/NG
  - Credible Phase II technical development plan

# Notional Vulcan Phase II Program Plan

## Phase II – Component and Subsystem Demonstration

- **Objectives**
  - Progressively mature design and technology required to validate program performance goals
  - Component and subsystem risk reduction testing and design trades
  - Updated engine performance model simulation
  - Preliminary Design Review (PDR) of CVC and inlet/nozzle configuration
- **Programmatics**
  - ~18 months duration
  - Risk reduction testing complete for all components and subsystems at full scale to include: combustors, valves, nozzles, materials, seals, TMS, TJ-CVC & CVC air metering & nozzle systems and others identified
  - Phase III proposal update to WBS level 4 details
- **Deliverable**
  - Quarterly Program Management Reviews (PMRs)
  - Interim CVC design review and Final PDR
  - Components test plans and reports
  - Propulsion performance predictions
  - An updated Phase III technical and cost proposal to WBS level 4
- **Criteria for Following Phase**
  - Meeting the technical objectives and DARPA DIRO G/NG
  - Availability of funds

# Notional Vulcan Phase III Program Plan

## Potential Phase III - CVC Demonstration

- **Objective**
  - Progressively mature design and technology required to validate program performance goals
  - Detail Design, fabrication and successfully demonstration of full scale CVC engine, flow path switching inlet and nozzle
  - Continue risk reduction testing activities
  - Validate performance capabilities of the CVC
  - Preliminary Design Review of the Vulcan System: Turbine, CVC, inlet and nozzle
- **Programmatics**
  - ~ 18 months duration
  - CVC Critical Design Review (CDR)
  - Successful full scale CVC Demonstration (w/flow path switching mechanism for inlet and nozzle)
  - Vulcan PDR
  - Phase IV proposal update to WBS level 4 details
- **Deliverable**
  - Quarterly PMRs
  - Interim Vulcan design review and final Vulcan PDR
  - Test plans and reports
  - Propulsion performance predictions
  - An updated Phase IV technical and cost proposal to WBS level 4
  - Criteria for following phase
  - Meeting the technical objectives and DARPA DIRO G/NG
  - Availability of funds

# Notional Vulcan Phase IV Program Plan

## Potential Phase IV – TJ-CVC Demonstration

- **Objective**
  - Progressively mature design and technology required to validate program performance goals
  - Detail design of the Vulcan System (full turbine + CVC propulsion module)
  - Fabricate and Integrate a full scale CVC engine with a turbine engine
  - Full scale demonstration of all 3 operating modes including flow path switching inlets and nozzle
  - Validate performance predicted in previous phases
- **Programmatics**
  - ~18 months
  - Vulcan CDR
  - Successful integrated propulsion system demonstration – direct connect configuration
- **Deliverable**
  - Quarterly PMRs
  - Interim Vulcan Design Review and Final CDR
  - Test plans and reports
  - Propulsion performance predictions

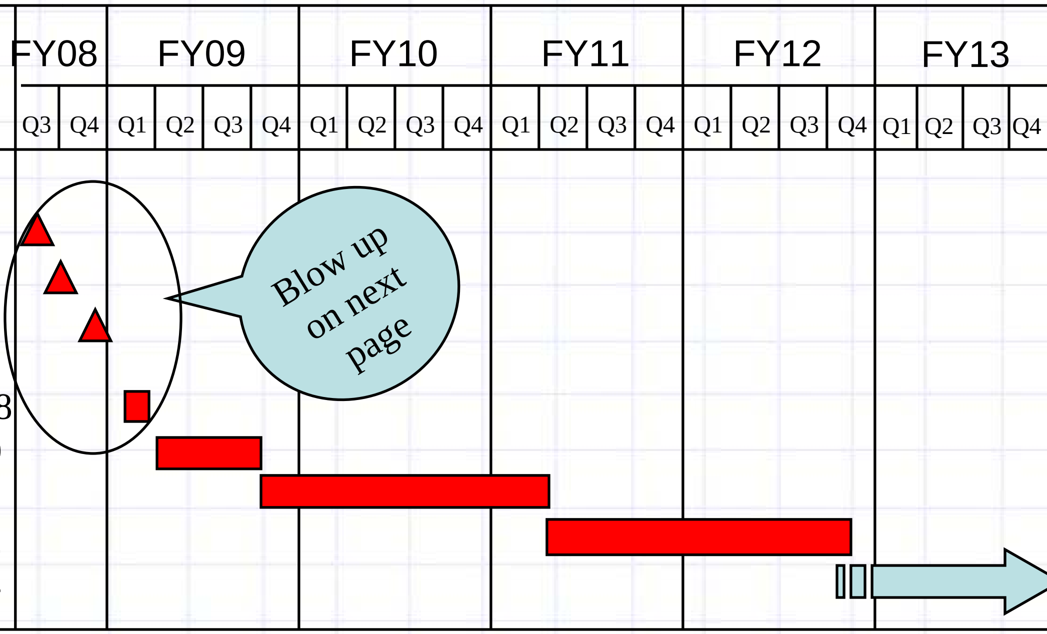
# Notional Acquisition Overview

## BAA Response Anticipated to Include:

- **Ability to meet program Go/No-Go metrics**
- **Overall Scientific and Technical Approach**
  - Technical innovativeness
    - Point of Departure Design
    - Feasibility/Substantiation
  - Development plan
    - Trade study and analysis plan
    - Risk management plan
    - Statement of work
    - Integrated master schedule
- **Potential Contribution and Relevance to the DARPA Mission**
- **Management and Program Team**
  - Program team
  - Management construct/corporate capabilities
  - Intellectual Property
- **Cost**
  - Completeness
  - Substantiations
  - Program risk (reasonableness)

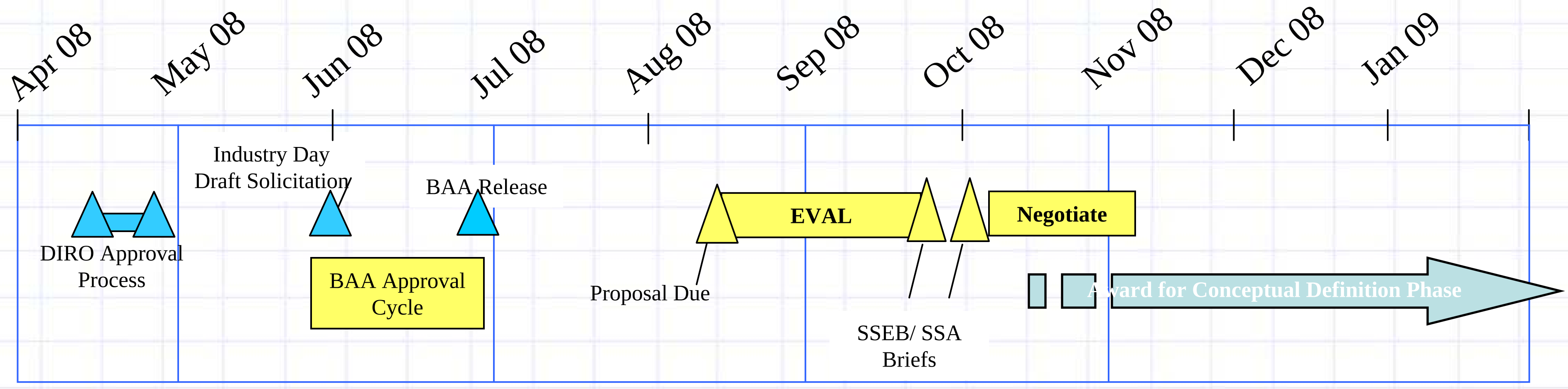
# Notional Program Schedule

| Task/Phase | Start | Finish |
|---|---|---|
| Industry Day Brief | 06/10/08 | |
| BAA Released | 06/30/08 | |
| Proposals Due | 08/11/08 | |
| BAA Negotiations | 10/06/08 | 11/06/08 |
| Phase I | 11/2008 | 06/2009 |
| Phase II | 07/2009 | 01/2011 |
| Phase III | 02/2011 | 08/2012 |
| Phase IV | 4QFY12 | 2QFY14 |




**Phase I -- Conceptual Definition (6+1+1 Month)**
**Phase II – CVC Component Demo (18 months)**
**Phase III – CVC Demo (18 Months)**
**Phase IV -- TJ-CVC Demo (~ 20 Months)**

# Tentative Term Acquisition Schedule



# Tentative Acquisition Schedule

| | |
|---|---|
| Industry Day | 10 June 2008 |
| BAA Release | 30 June 2008 |
| Proposals Due | 11 Aug 2008 |
| Evaluation Complete | 29 Sep 2008 |
| Negotiations & Awards | Oct 2008 |

http://www.darpa.mil/tto/solicitations.htm

Questions submit to: BAA08-53@darpa.mil

# BAA Process

DARPA/CMO

# BAA PROCESS

Solicitation is released utilizing Broad Agency Announcement procedures IAW FAR 35.016

- BAA and any amendments posted in FEDBIZOPPS
- BAA covers all info needed to propose
- BAA allows for a variety of technical solutions
- Individual Proposals evaluated in accordance with the BAA and not evaluated against each other
- Funding Instruments will be Procurement Contracts and/or Other Transaction Agreements. Grants and Cooperative Agreements will not be available under this solicitation.
- **Following the proposal instructions assists the evaluation team to clearly understand what is being proposed and supports a timely negotiation.**

# BAA PROCESS

**NOTE:**

- Organizational Conflict of Interest & Procurement Integrity language
- Central Contractor Registration (CCR), Online Representations and Certifications Application (ORCA), & Wide Area Workflow (WAWF)
- Subcontracting Plan Requirements
- Include detailed cost breakdown for subs whose costs are, or exceed, 10% of total proposed price
- Data Rights Assertions - Assert rights to <u>all</u> technical data & computer software generated, developed, and/or delivered to which the Government will receive less than Unlimited Rights
    - Assertions for Prime and Subs
    - Justify "Basis of Assertion"
    - This information is assessed during evaluations

# BAA PROCESS

- EVALUATION/AWARD
  - Government reserves the right to select for award all, some, or none of the proposals received and to award without discussions
  - Government anticipates making multiple awards
  - No common Statement of Work - Proposals evaluated on individual merit and relevance as it relates to the stated research goals/objectives rather than against each other
  - Only a duly authorized Contracting Officer may obligate the Government

# BAA PROCESS

- COMMUNICATIONS
  - From now to receipt of proposals – No restrictions, however, Gov't (PM) shall not dictate solutions or transfer technology
  - After Receipt of Proposals – Government (PM/PCO) may communicate with offerors in order to seek **clarification**, obtain **confirmation** or **substantiate** a proposed approach, solution, or cost estimate
  - Informal feedback may be provided once selection(s) are made