REUSE OF A COLD WAR SURVEILLANCE DRONE TO FLIGHT TEST A NASA ROCKET BASED COMBINED CYCLE ENGINE

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ABSTRACT

Plans for and early feasibility investigations into the modification of a Lockheed D21B drone to flight test the DRACO Rocket Based Combined Cycle (RBCC) engine are discussed. Modifications include the addition of oxidizer tanks, modern avionics systems, actuators, and a vehicle recovery system. Current study results indicate that the D21B is a suitable candidate for this application and will allow demonstrations of all DRACO engine operating modes at Mach numbers between 0.8 and 4.0. Higher Mach numbers may be achieved with more extensive modification. Possible project risks include low speed stability and control, and recovery techniques.

INTRODUCTION

As the center for excellence in propulsion, the NASA George C. Marshall Space Flight Center's (MSFC) charter is to safely conceive, develop, and test new transportation systems for low cost access to space. Operability is a key consideration in future low cost propulsion systems. This can never be fully tested in ground based test facilities and requires, instead, a flight test bed. Low cost, low development effort flight test beds are highly desirable since the focus is to develop new engines, not new test beds. This paper addresses an investigation in progress at MSFC to use an existing Mach 3 vehicle, the D21 drone, as a test bed for the NASA DRACO Rocket Based Combined Cycle engine now in development. The need is to test the engine in flight in its three modes of operations: air-augmented rocket, ramjet, and rocket. Studies at MSFC and by MSFC contractors have shown that, with modifications, the D21 is capable of supporting RBCC operation from Mach 0.8 to Mach 4.0 and beyond Mach 4.0 with more extensive modification. Use of the D21 supports NASA's search for safe, faster, better, cheaper solutions to technology development.

THE D21 DRONE[1]

Built in the 1960's by Lockheed Skunk Works, 17 of the D21 surveillance drones remain in existence today. The drones configuration, availability, and performance make it an attractive candidate as a flight test bed for new near-term aerospace technologies, especially new engines.

The Gary Powers incident of 1960 impressed upon the US the need for higher flying, faster, and even unmanned methods of surveillance. Lockheed Skunk Works began development of just such a device in 1962, a drone called the D21 and later the D21B. The D21 incorporated much of the technology developed for the A12 (later to be called the SR71) and many technical challenges were solved during its development. The D21 was flown between 1964 and 1971 with limited success largely due to the complex launch and camera payload recovery operations.

The D21 Configuration

The D21 is characterized by a highly swept, chined delta wing blended into a titanium monococque body with titanium skins and single vertical tail. Dimensions and performance are shown in Table 1. Wing leading edges, which run the length of the vehicle, were manufactured of a silicon composite material. A modified RJ43-MA-3 Bomarc engine, a ramjet made by Marquardt, was selected to power the vehicle. Air was delivered to the engine from a fixed geometry, axisymetric, mixed compression inlet through a titanium duct running through the center of the vehicle. The inlet to the Bomarc engine was left in place, so the D21 actually has two inlets. JP-7 fuel was stored in the fuselage and into the wings in typical wet wing fashion. Bulkheads separate the fuel into three sections for CG control. The inlet duct transects these tanks and is separated from the fuel by a nitrogen filled interspace. An auxiliary power unit powered by ram air is used for vehicle electrical power and cooling of the avionics.

Control surfaces were powered by a hydraulic pump. The reconnaissance payload, automatic flight control system, telemetry electronics, recovery beacons, and parachute system were configured into an ejectable hatch assembly on the underside of the vehicle behind the inlet spike. Hardpoints on the underside of the vehicle provided the means to mount the D21 to the back of the M21 ("M" for mothership and "D" for daughter).

Figure 1 D21 with M21 Mothership

Table 1 – D21B Specifications

Length	42.9 feet
Wingspan	19.1 feet
Height	7.1 feet
Cruise Speed	Mach 3.2 plus
Cruise Altitude	65,000 to 95,000 ft
Range	3,000 nmi
Avg. Skin Temp.	650 °F
Gross Weight	11,200 lbs
Empty Weight	5,300 lbs
Max Fuel Load	5,900 lbs JP-7 (912 gallons)

D21 Operations

The original mission profile was to ferry the D21 to a launch site aboard the M21 as shown in Figure 1. At Mach 1.2 the engine of the D21 was started to help accelerate the mated vehicles to the Mach 3 launch condition. The D21 tanks were topped off, and the drone was jettisoned for its 3000 nautical mile, Mach 3.3 pre-programmed reconnaissance flight. At the end of the run, the drone entered an unpowered descent, ejected the hatch assembly at 60,000 feet, and self destructed at 52,000 feet. Consequently, the D21 has no landing gear. A parachute system on the ejected hatch assembly allowed it to be recovered in the air by a waiting Lockheed C130.

Three successful launches were made from the M21, but the fourth launch attempt, in July of 1966, was a failure. The D21 collided with the M21 on release. The pilot and launch system operator ejected as the M21 broke up in mid-air over the Pacific Ocean near Point Magu. Only the pilot survived. Recovering from the accident, Lockheed began work in earnest to launch the D21 from a B52 Stratofortress . The new drone, designated the D21B, required dorsal mounting hooks to mate with an attach pylon on the B52 wing. The ventral hard points were used to attach a solid rocket booster to the D21B. The booster, also made by Lockheed, provided an average thrust of 27,300 pounds over 87 seconds and lofted the D21B from 38,000 feet at Mach 0.8 to 80,000 feet and Mach 3.2 plus. At 30 inches diameter and 531 inches length, the 13,286 lb booster was a few inches longer than the drone itself.

The D21 Today

Of the 38 drones produced, 17 remain today. Three of these are stored on the dry lakebed at the NASA Dryden Flight Research Center. A precursory visual inspection showed the NASA Dryden vehicles to be in relatively good shape. Inlet and engine areas appear clean and well preserved. The composite leading edge elements have degraded from exposure. Health of the internal components is unknown and can only be determined with some disassembly of the vehicle. The location of the hatch assemblies with the high value avionics is unknown. They are assumed to have been scrapped for parts. Ground support equipment for the D21 most likely met the same fate. Drawings and test reports from the D21 program are maintained at Lockheed Martin Skunk Works.

THE DRACO RBCC ENGINE

DRACO is an acronym for Demonstration of Rocket and Air-breathing Combined-cycle Operation. The DRACO engine project is currently underway at various NASA centers, with a goal of developing and flight testing a hydrocarbon fueled RBCC engine by the end of 2005.[2] The initial DRACO flowpath design effort is being led by Glenn Research Center (GRC), while the engine systems and flight weight flowpath development are led by MSFC. Members of the DRACO team, representing GRC, MSFC and Dryden Flight Research Center (DFRC) established the baseline flowpath concept during a series of meetings in August 1999.[2] The DRACO flowpath concept consists of a variable geometry (translating center-body) inlet, a set of concentric-ring fuel injectors, a multi-thruster rocket assembly, a ram combustor and a variable throat geometry nozzle.

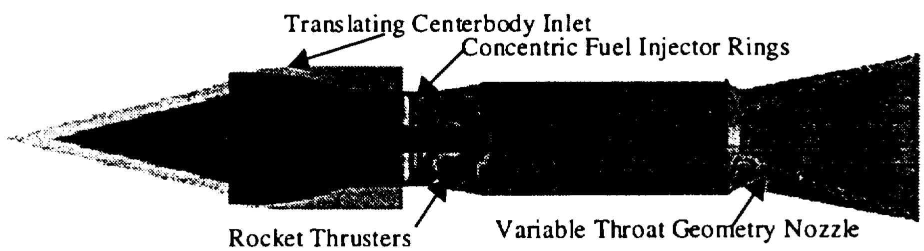

Figure 2 DRACO Engine Concept

The DRACO flowpath concept is an ejector-ramjet cycle with three distinct operating modes: Air Augmented Rocket (AAR) from Mach 0 to approximately 3.0, ramjet from Mach approximately 3.0 to 6.0, and rocket for operation above Mach 6.0. Figure 2 is a representation of the current DRACO engine concept.

The concentric ring fuel injectors are up-stream of the rocket thrusters allowing the thrusters and their support struts to act as bluff body flame holders in the ramjet mode. This geometry also eliminates the requirement to remove flame holding devices during AAR and pure rocket mode. The rocket thruster assembly produces approximately 10,000 lbf thrust at sea level static conditions. As the inlet Mach number increases, the pumping performance of the thrusters increase the flow of ambient air through the inlet. This air later burns in the ram combustor section. The addition of captured ambient air to the DRACO cycle increases Isp and thrust until at approximately Mach 3, the rocket thrusters are shut down and the engine is operated in a ramjet mode. Here, all the oxygen consumed within the flowpath is provided by the inlet. Hot sections of the DRACO flowpath are regeneratively cooled by the fuel supplied to the thrusters or ramjet combustor.

Preliminary performance modeling of the DRACO engine has been accomplished using the SCREAM RBCC simulation code.[3] The results of this performance modeling have been used to perform vehicle trajectory analyses.

D21 MODIFICATIONS

Short term study contracts, awarded to Orbital Sciences Corporation and Lockheed Martin Astronautics, investigated the feasibility of modifying the D21B to flight test the DRACO engine. Modifications to the D21 include integration of DRACO engine, and the addition of oxidizer tanks, modern avionics systems, actuators, and a vehicle recovery system. Figure 3 is a representation of the D21B with the DRACO engine integrated.

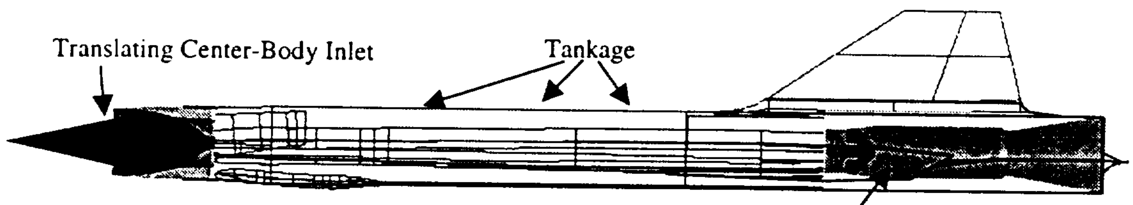

Figure 3. D21/DRACO Vehicle Engine Integration

Results from the contracts[4,5] as well as MSFC studies suggest that a modified D21B will allow self powered demonstration of all DRACO operating modes. However, structural and temperature limitations of the air duct limit maximum Mach number in air breathing mode to between 3.5 and 4. Modification of the inner duct material may extend the air breathing capabilities to $M > 4$. External surfaces of the vehicle also limit Mach number due to temperature constraints. However, this issue may be resolved by the application of modern thermal protection systems.

Rocket thrusters within the DRACO engine require the addition of oxidizer tanks to the D-21 vehicle. Tank modification concepts range from unmodified outer mold line (OML) approaches with imbedded oxidizer tanks to modified OMLs with external tankage. External tankage increases vehicle weight and drag but allows additional propellant to be carried and decreases engineering complexity. Also, external tankage allows greater flexibility with respect to propellant selection. Unmodified OML concepts allow greater acceleration due to lower gross mass and lower drag. However, these concepts limit demonstration duration, due to propellant volume constraints, and possibly limit the ultimate Mach number achieved.

Multiple recovery techniques have been investigated. Techniques range from parachute/parafoil recovery, main skids and nose wheel lakebed recovery, and conventional all wheeled runway recovery. Early investigations have nearly eliminated the parachute/parafoil option due to existing volume constraints. Decisions between lakebed and runway type recoveries will require low speed aerodynamics, stability and control testing. No low (landing speed) wind tunnel data currently exists for the D21 airframe. Because the D21 was not originally designed to fly in this low speed regime, landing characteristics of the vehicle are currently considered a high priority issue.

While the possibility for powered horizontal runway takeoff exists, air launch from the NASA DFRC B52 is currently considered the baseline. B52 launch relieves requirements for a sled or full wheeled landing gear, and provides a head start toward the high priority AAR to RAM mode transition demonstration.

DRACO VEHICLE PERFORMANCE

DRACO engine performance simulations and vehicle concept information, including mass properties, propellant loads and aerodynamics are used to simulate complete vehicle system performance. Figure 4 presents two typical DRACO Vehicle trajectory simulation results for an unmodified OML concept.

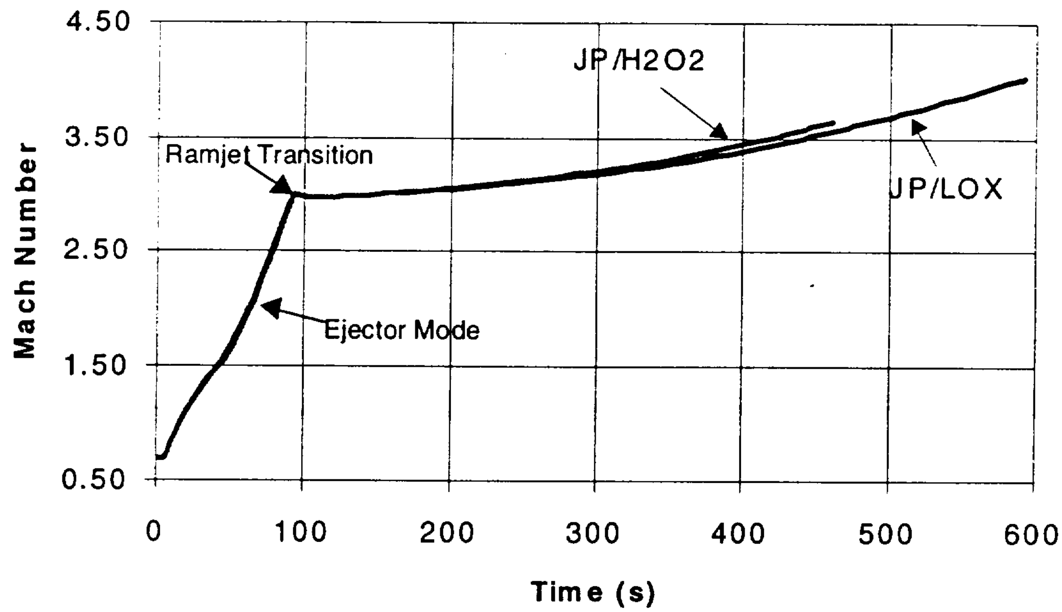

Figure 4. Typical Trajectory Results for the Unmodified D21 OML Concept

The trajectory begins at M = 0.6 (at t = 0). At this point the DRACO vehicle is dropped from the B52 and the engine is ignited. The vehicle accelerates under AAR mode to a Mach number of approximately 3. Next the thrusters are shut down and the vehicle continues to accelerate in RAM mode. The trajectories for both propellant combinations are concluded with enough propellant remaining for a five second rocket only demonstration. The results presented in Figure 4 indicate that the JP/LOX propellant combination slightly out performs the JP/H2O2 combination. This performance difference is mainly influenced by the usable propellant volume restrictions of the unmodified OML concept. Results form the modified OML concepts, that allow increased propellant volumes, indicate more comparable performance between the two combinations. Overall trajectory analysis indicates that a D21B based flight testbed will be capable of demonstrating all the DRACO operating modes and reaching maximum Mach numbers of 4.0. Higher Mach numbers may be achievable with additional modifications, such as a new air duct and thermal protection systems.

CURRENT PLANS

Current plans for the DRACO vehicle effort are to continue the required investigations and trades to develop a high confidence vehicle concept within the next several months. The details of this concept will be baselined and system requirements will be developed, at which point a detailed design phase will begin. Current uncertainty over D21 aerodynamics, stability and control and landing procedures will be addressed by two near term tests. Preliminary wind tunnel testing will be performed to determine lift and drag characteristics throughout the DRACO/D21 flight regime and anchor the understanding of available archival D21 aero data. In addition, DFRC will flight test an instrumented, dynamically scaled, remotely piloted model of the D21B. Data from these model flight tests will provide critical stability and control information as well as low speed and ground affect aerodynamics.

While the ultimate goal is to develop a flight test bed for the DRACO RBCC engine, there is a desire for the vehicle development and fabrication to proceed and demonstrate captive carry/drop test flights prior to availability of the DRACO flight engine. This demonstration will likely be unpowered, and make use of mass simulators to account for the DRACO engine and other propulsion system components. Early drop tests will demonstrate the modified vehicle flight characteristics, updated avionics systems, and the vehicle recovery system, thus limiting the risk that must be accepted by the DRACO project. Early demonstrations will allow a flight proven vehicle to be available for engine integration prior to the initial DRACO flight demonstrations planned for 2005.

SUMMARY AND CONCLUSIONS

The D21 is a Mach 3+ proven flight system and current analysis results indicate that it is a suitable candidate for transformation into the DRACO flight testbed. The modified D21B will allow demonstrations of all engine operating modes at Mach numbers between 0.8 and 4.0. Higher Mach numbers may be achieved with more extensive modifications including a new air duct and thermal protection systems. Possible project risks include low speed stability and control, and recovery techniques. However, these issues should be resolved by planned wind tunnel and remotely piloted vehicle testing. Finally, using an existing, flight proven airframe as the basis for the DRACO flight testbed concept will likely reduce schedule and cost growth risks, and is consistent with NASA's needs for safe, faster, better, cheaper innovation.

ACKNOWLEDGMENTS

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