NASA KSC/AFRL
Reusable Booster System (RBS)
Concept of Operations (ConOps)

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RBS Study Overview
RBS Study Objectives

• Provide RBS Ground Concept of Operations (ConOps) to center on rapid turnaround & launch of a two-stage partially reusable payload delivery system (8-hours between launches)
  – Operational responsiveness to meet aggressive timelines
  – Vehicle performance trades considered for increased operability
• Develop rapid ground processing (aircraft like) concepts
  – Flight element turnaround & readiness between flights
  – Flight element integration, transportation and handling, interfaces (flight elements, pad, etc.)
  – Launch site operations activities definition and timeline development
  – High surge rate
• Identify areas for follow-on study, technology needs, and proof-of-concept demonstrations
System Design Requirements

- Integrate a separate payload, upper stage and booster, and ready the vehicle for launch within 2 hours from call-up
- Re-service a reusable booster for call-up within 6-hours after runway wheel stop

**Booster**
- 110' L, 14' Dia., 60' wing span
- 130K lbs dry, 750K lbs fueled with RP1 & LO2

**Upper Stage**
- 110' L, 9' Dia.
- 50K lbs dry weight for RP1 & LO2 (fueled weight ~300K)
- 300K lbs solid propellant version

**Payload**
- 9' Dia. fairing maximum
- 15K lbs gross lift off weight

*Ability to provide an 8-hour between flight turnaround capability is complex and relies on significant technical enablers*

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Rapid Turnaround Enablers
System Functional Integrity

- Maintaining system functional integrity between flights is critical as it allows one-time vehicle certifications
  - Avoids repetitive flight certification testing and reviews to verify mission flight readiness
  - Standardized booster flight regime reduces need for specialized booster mission hardware or re-certification
- Minimizing vehicle intrusion enables functional integrity
  - Utilize on-board systems to verify system health (aircraft-like)
  - Only repair malfunctioning systems as needed—minimize testing
  - Design robust systems that require minimal servicing, testing and are fault tolerant

*Functional integrity essential to maintain operational responsiveness by limiting amount of work to be completed between flights*
• Overarching themes employed throughout the study to enable system responsiveness
  – Maintain flight system integrity to minimize amount of work performed between flights
    • Utilize on-board systems to verify system health (aircraft approach)
    • Only repair malfunctioning systems – minimize additional testing
  – Minimal manual interaction
    • Autonomous, self-diagnostic, self-aligning systems and features
  – Simplified connections between flight elements & ground/flight systems
    • “Push and click” flight/ground structural connections
  – Rapid turnaround capability
  – System operational responsiveness
  – Horizontal processing
    • Eliminates large, complex & costly vertical facilities
    • Eliminates crane operations & complex access
ConOps Development
• Significant ground rules, assumptions and considerations:
  – System functional integrity (structural, fluid, electrical) must be maintained between flights to minimize work content
  – Booster, Upper Stage & Payload are separate prior to call-up
  – Aircraft-like three-level maintenance concept separates line level activity from off-line activity (intermediate/depot) by design
    • Line level maintenance focus ensures minimal tasking/testing for max responsiveness
  – No thermal protection systems requiring maintenance between flights
  – Minimal serviceable propellants, fluids and gases
    • Confined to RP-1/LO2/ethanol/GN2 only
    • RP-1/LO2 loaded at pad in vertical configuration
    • No toxic propellants (hypercals) requiring hazard clears, specialized personnel protection, or complex support equipment
  – Minimal material hazards and processing induced hazards
  – No distributed hydraulics or active cooling fluid loops
  – Ground concepts applicable to multiple launch & landing site locations

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ConOps Development Approach

REUSABLE BOOSTER SYSTEM (RBS) GOALS & OBJECTIVES (Responsiveness, Turn Time, Call-up, etc.)

Ground Systems
- General concept for vehicle processing (free of system design details)
- Elements of ground system concept (examples)
  - Vehicle Handling, Transportation, & Assembly Concept
  - Propellant Servicing & Transfer Concept
  - Power & Communication Concept
  - Vehicle & Payload Integration
  - Transporter/Erector
  - Exhaust Management
  - Flight Hazards
  - Launch Release

Maintenance Concept

Flight Systems Design

Vehicle Design Input

Vehicle Design

Ground Operations Timeline Assessments & Operational Facility Flow

Concept of Ground Ops
- Booster Landing & Turnaround
- Payload & Upper Stage Operations
- Call-up, Vehicle Integration & Launch

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Operational Flow

Pre-Call-up (6 Hours)

Booster Turnaround & Integration Facility

Post Call-up (2 Hours)

Booster Turnaround Processing Configuration

Booster Turnaround on Adjustable Jackstands

Booster Mated to Erector

Booster Ready for Call-up

Call-up Integrate Booster to Mission Set

Mission Set Integration to Booster

Ready for Move to Pad

Payload Storage Facility

Payload Ready for Call-up

Mission Set Integration Facility

Payload Integration to Upper Stage

Payload Transfer to Booster Integration Facility

Post Call-Up Mission Set Integration

Launch Pad

Vertical Rotation & Integration with Pad

Mated to Pad Ready for Erector Removal

Ready for Launch

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Operational Flow/Systems Concepts During Turnaround (L-8 hours – L-2 hours)
Runway Concept

- Returning booster attached to "towbarless" tug (or similar) for movement from runway
  - "Towbarless" provides for rapid attach and movement
    - Minimizes steering/braking concerns
  - Booster to be removed as soon as possible for other runway traffic
  - Towed from runway to Booster Turnaround & Integration Facility which starts turnaround operations

Excess cryogenic propellants evacuated & on-board purges established during flight to minimize ground hazard concerns & allow rapid "aircraft-like" tow

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Booster Turnaround Concept

- Six-hour turnaround abides by line-level maintenance philosophy
  - Autonomous vehicle health monitoring
    - Identifies level of required maintenance
    - Minimizes detailed tests & inspections
  - Maintain functional integrity throughout turnaround to avoid repetitive flight certification
    - Minimizes intrusion into vehicle
    - Include robust, self-monitoring systems that require minimal servicing and testing

- Vehicle is positioned on adjustable jack stands for turnaround operations:
  - Configure systems & connect required ground services (fluid, purge, power, data)
  - Replenishment of spent systems (GN2, ethanol, etc)
  - Booster adjusted to erector mating height for:
    - Landing gear retraction
    - Connection to booster erector

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Booster Handling Concept
(Assembly and Transportation)

- Transporter/erector translates horizontally under jack supported Booster for structural connection
  - Simplified, autonomous aft three-point connection
  - Forward attach arms grapple booster with simplified self-aligning roller system
  - Launch mount is integral to transporter/erector to minimize pad flight to ground mating operations
  - Ground servicing umbilicals may also be connected

- Horizontal mating provides easier, more repeatable alignment process
  - Avoids time-consuming alignment complexities associated with crane lifts and suspended load issues
  - Provides better load control during mating operations
  - Rail system assists in initial alignment

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Payload Preparation Concept

- Payload is in a "ready mode" at call-up – fully encapsulated with mating adapter installed
  - Payloads are maintained separately from upper stage & pre-serviced
  - Mission planning/analytical integration performed prior to call-up
  - Payload transfer and integration to Upper Stage occurs at call-up
- "Standard Payload Adapter" (SPA)
  - Unique interface to payload while providing a standard interface to Upper Stage
  - Considered an Upper Stage item and is expended (not recovered)
- No payload unique services provided after call-up
  - Ground umbilical thru SPA during storage but not for launch
Upper Stage Handling Concept
(Transportation & Assembly)

- Upper stage transporter may serve as a manufacturing base and transporter
  - Upper stage may be solid or liquid
  - Upper stage delivered in a "ready for call-up" condition
  - Minimal planned work/services provided on upper stage after delivery
  - Robust, autonomous, self-diagnostic system needed for the upper stage
- Horizontal mating provides easier, more repeatable alignment process
  - Avoids alignment complexities associated with crane lifts
  - Mitigates suspended load issues
  - Provides better load control during mating operations
  - Rail system assists in initial alignment

- Transporter assists in alignment during payload and booster connection
  - Autonomous three-axis positioning control function
Operational Flow/Systems Concepts
Post Call-up
(L-2 Hours through Launch)
Vehicle Assembly Sequence at Call-Up (L-2 hours)

Under-slung upper stage reduces complexity & hazards associated with lifting over booster for mate & access for working at heights

Upper stage transporter & booster erector lock together for structural integrity during transport/rotation

Payload mated to Upper Stage

Upper Stage mated to Booster

Horizontal Mating Provides Easier, More Repeatable Process
- Rail system assists in initial alignment
- Complex crane lift alignment issues are avoided
- Suspended load concerns are mitigated
- Better load control during mating operations

Vehicle travels on rails to pad

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Rotation and Mate to Pad Concept

- Transporter launch mount connects to pad hinge-points once vehicle and transporter arrive at pad
- Pad rotation hydraulic ram (not shown) is utilized to rotate the transporter/erector with the booster and upper stage to vertical
- Pad services to vehicle minimized for simplicity and responsiveness
  - Booster/upper stage services established through auto-coupled umbilicals to launch mount or directly to vehicle
  - Aft connections eliminate need for umbilical towers, manual ops & minimizes pad turnaround

Self aligning aft rise-off umbilical design for Booster and Mission Set (US/PL)
- Decreases time during call-up due to automated coupling versus manual operations
- Launch blast protection decreases pad turnaround time - reduces launch damage risk & exposure to launch plume environment
Post-Rotation/Mate Pad Operations

- Forward support legs are released and rotated to horizontal via pad hydraulic ram system (not shown) & removed from pad prior to launch
- Booster transporter/erector aft launch mount portion remains at pad

Vehicle on launch mount & ready for launch

Erector legs rotated to horizontal & removed from pad - launch mount remains

- Vehicle power is applied and final system checkout commences
- Propellant loading occurs after leak checks & system conditioning
- Launch occurs after autonomous system checkout

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Main Propulsion/Propellants Concept

- Ethanol load (attitude control) completed in horizontal orientation during turnaround and prior to call-up
- GN2 two-stage pressurization with partial load during turnaround then flight load at pad (technology challenge)
  - Heat dissipation management
- Modular engine pod concept for aircraft-like replacement
- Maintain positive dry GN2 purge on main propulsion system during both flight/ground operations to mitigate moisture concerns and alleviate additional verification testing
- Propellants launch-ready after 30-minute fill (technology challenge)
  - Rapid vehicle pre-chill down utilizing new concepts
  - Early chill down of LO2 ground transfer lines
  - LO2 & RP-1 both loaded at pad in parallel
  - Booster & Upper Stage filled simultaneously
Avionics/Power/Control Concept

- On-board health management identifies level of maintenance required
- Individual avionics power buses allow flexibility of different avionics power configurations (e.g. isolate high power loads and minimize thermal loads)
- Standardized booster flight planning to simplify flight software development and subsequent load/checkout
- Battery powered actuators and avionics for flight eliminate need for more complex power generation systems which increase turnaround
  - Rapid re-charge/multiple cycle capability needed
- Two ground-supplied power modes:
  - Maintenance mode provides ground-supplied power to essential avionics
  - Standby mode provides limited power for propellant/engine GN2 purge conditioning
- Simple/quick ground power connection(s) convenient for both horizontal and vertical operations

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Recommendations & Summary
Recommended Ground and Vehicle Demonstrations

- Vehicle Handling, Transportation, and Assembly
  - Upper Stage to Booster Flight Connection and Release System Repeatability/Responsiveness
  - Booster Transporter/Erector Connection Repeatability/Responsiveness
  - Upper Stage Transporter/Erector Connection Repeatability/Responsiveness
  - Booster Automated Ground Jacking System
  - Booster to Ground Support Interfaces and Release Systems
- Rapid LO2/RP-1 propellant conditioning and loading
- Autonomous operations for manpower/timeline reduction
- Rapid high pressure nitrogen system loading/heat dissipation
- Payload readiness and simplified adapter demonstrations
- Launch exhaust management systems

Frequent & Multiple Ground Demonstrations are Critical to Ensure Rapid/Aggressive Operability is Achievable

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Overall Recommendations

• Include Responsive Operations Expertise Throughout the Flight & Ground System Design Process
• Pursue One-Time Vehicle Certifications versus Flight-by-Flight
• Build Prototypes and Perform Ground Operations Demonstrations
• Conduct Successful Phased Maintenance Demonstrations
• Study Flight Element Pre-Integration Options
• Investigate Effect of Upper Stage/Payload Dry Mass on Responsiveness
• Account Early for Ground Service Interfaces and Commodities
• Investigate Facility Location/Hardening Effects on Transport Selection
• Optimize Number of Vehicles, Facilities & Ground Hardware Needed to Reduce Turnaround/Launch Timeline Risk
• Follow-on Studies and Analysis for Propellant Logistics

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Summary & Conclusions

- Rapid space vehicle preparation for flight is challenging and does not exist today (weeks/months vs hours/minutes)
- Inclusion of ground system enabling concepts into vehicle design are essential in reducing turnaround/call-up times between flights
  - One time flight vehicle certification versus flight by flight cert
    - Maintain system functional integrity between flights (aircraft-like concept)
  - Willingness to trade system performance for operability
  - Autonomous, self-diagnostic, self-aligning features
  - Minimal test and checkout between flights
  - Simplified connections between systems
  - Horizontal versus vertical processing
- Ground system demos vital to system responsiveness success
  - Demonstrations to retire risk and to prove viability/repeatability
- Ground system design approach critical to the achievement of a rapid turnaround/launch of the RBS system
Backup
- Booster carries expendable upper stage separated at ~Mach 5
- Booster performs "rocket-back" maneuver to set up glide return to runway in ~12min
- Flight performance trades considered to ensure rapid turnaround
  - Non-traditional approach to ground system design
Maintenance Concept

• Three-Levels of Maintenance Definition
  – Line-Level—Direct call-up, launch, landing & turnaround ops
  – Intermediate-Level—Minor overhaul, time-consuming trouble-shooting and repair, and periodic maintenance. Greater facility-provided access and services available for intrusive maintenance activities, compartment entry by repair technicians, etc. (May or may not be at launch site)
  – Depot-Level—System upgrades, long-term maintenance, intrusive repairs, and inspections occur

Vehicle design must be compatible with this operational philosophy to ensure repeatability and rapid preparation

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Managing Timelines & Controlling System Responsiveness

Program
Responsiveness Need/Goal

Timeline Allocations → Design Process → Timeline Assessments

Responsive System Design

Ops Analysis Cycle:

- Assess operational requirements & system design (flight & ground) simultaneously
- Iterative process continually assesses timeline and performs design corrective action to achieve objective
- Include operations experts throughout process

All system trades must be held accountable to timeline assessment process

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