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

RBS ConOps Study Team

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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

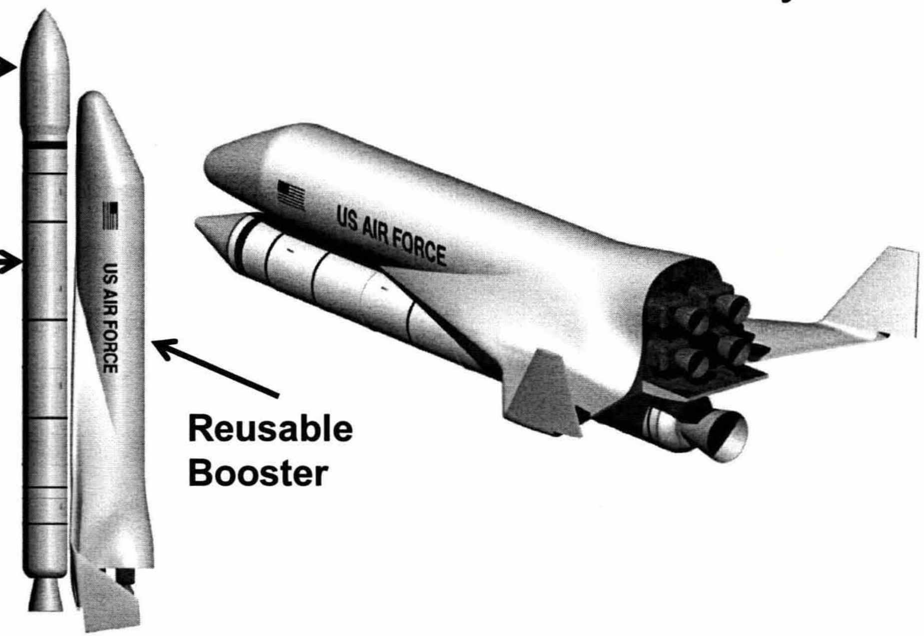
- 110' L, 14' Dia., 60' wing span
- 130K lbs dry, 750K lbs fueled with RP1 & LO2

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

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

Critical Responsiveness Enablers

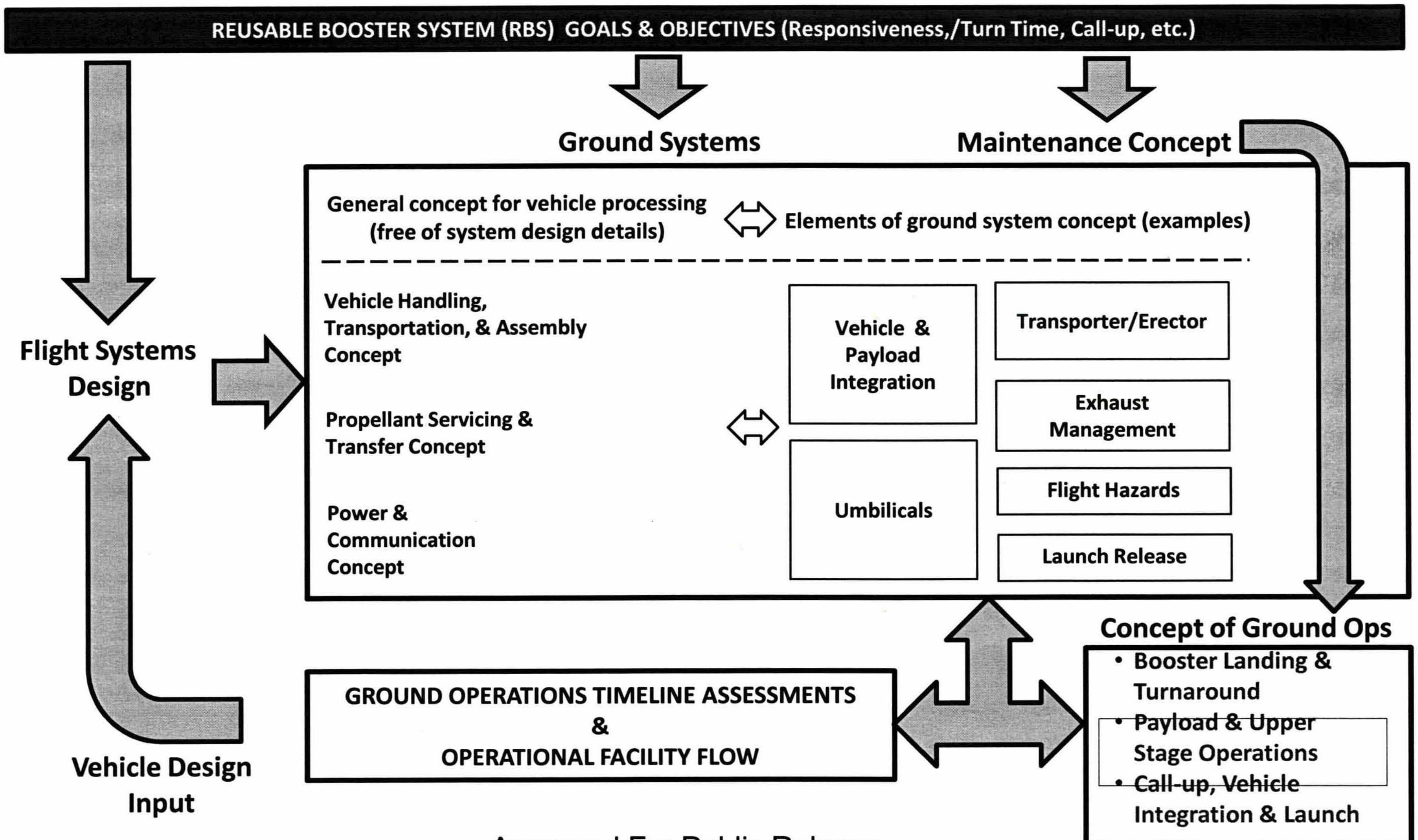
- Overarching themes employed throughout the study to enable system responsiveness
  - Maintain flight system integrity to minimize amount of work performed between flights
    - Utilize on-board systems to verify system health (aircraft approach)
    - Only repair malfunctioning systems – minimize additional 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

RBS Study Ground Rules & Assumptions

- 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 (hypergols) 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

ConOps Development Approach



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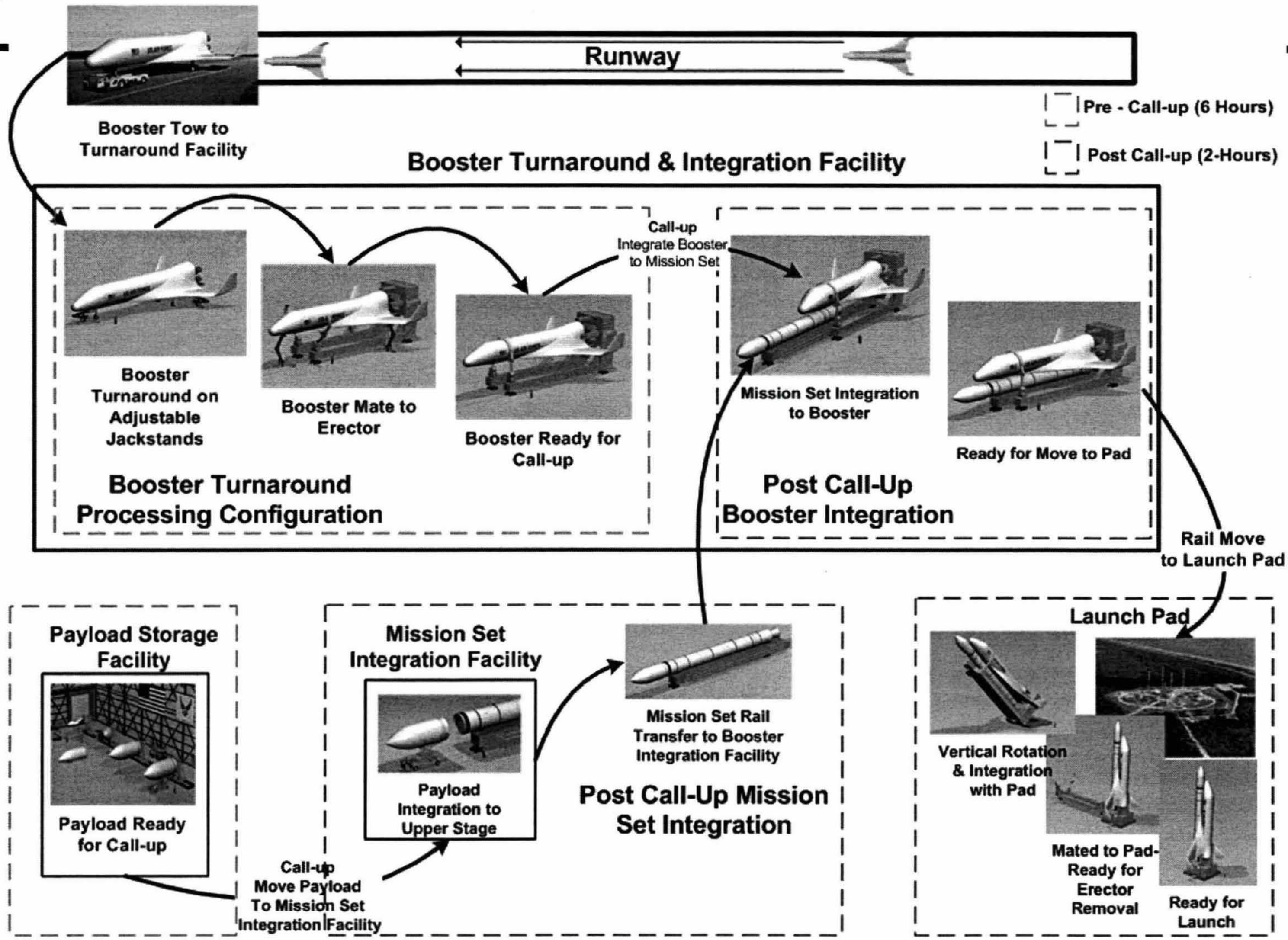
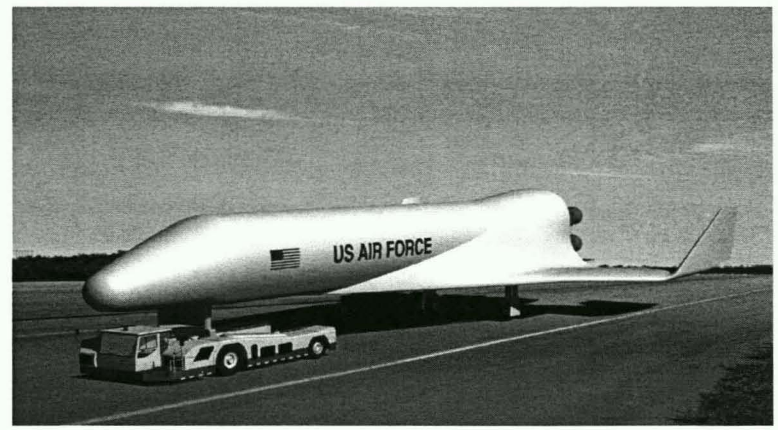
Operational Flow



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

Runway Concept

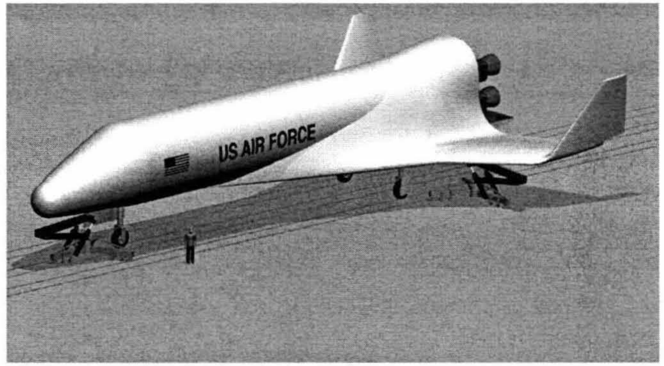
- Returning booster attached to "towbarless" tug (or similar) for movement from runway
  - "Towbarless" provides for rapid attach and movement
    - Minimizes steering/braking concerns
  - Booster to be removed as soon as possible for other runway traffic
  - Towed from runway to Booster Turnaround &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

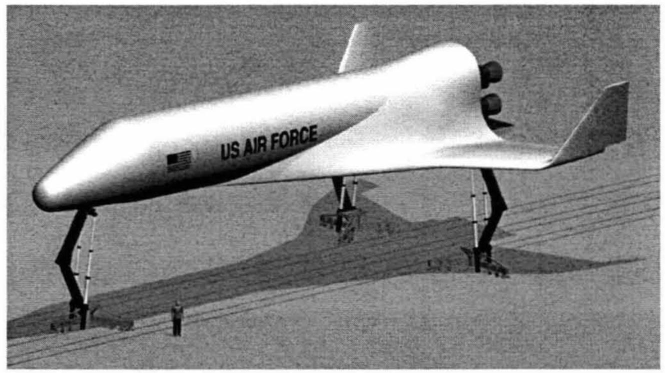


Excess cryogenic propellants evacuated & on-board purges established during flight to minimize ground hazard concerns & allow rapid "aircraft-like" tow

Booster Turnaround Concept

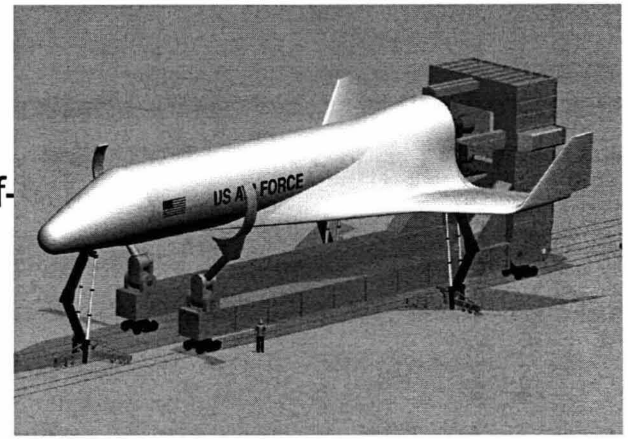
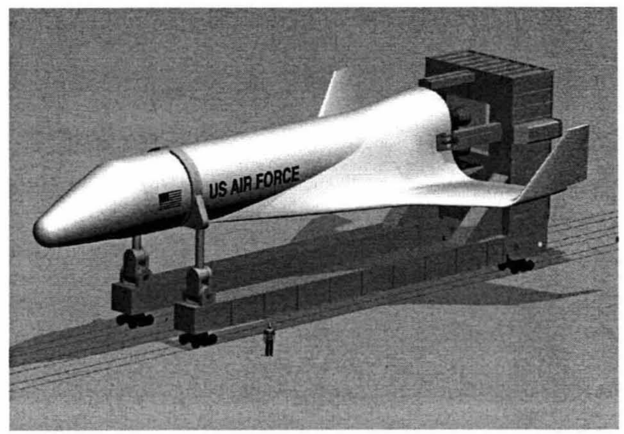
- Six-hour turnaround abides by line-level maintenance philosophy
  - Autonomous vehicle health monitoring
    - Identifies level of required maintenance
    - Minimizes detailed tests & inspections
  - Maintain functional integrity throughout turnaround to avoid repetitive flight certification
    - 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





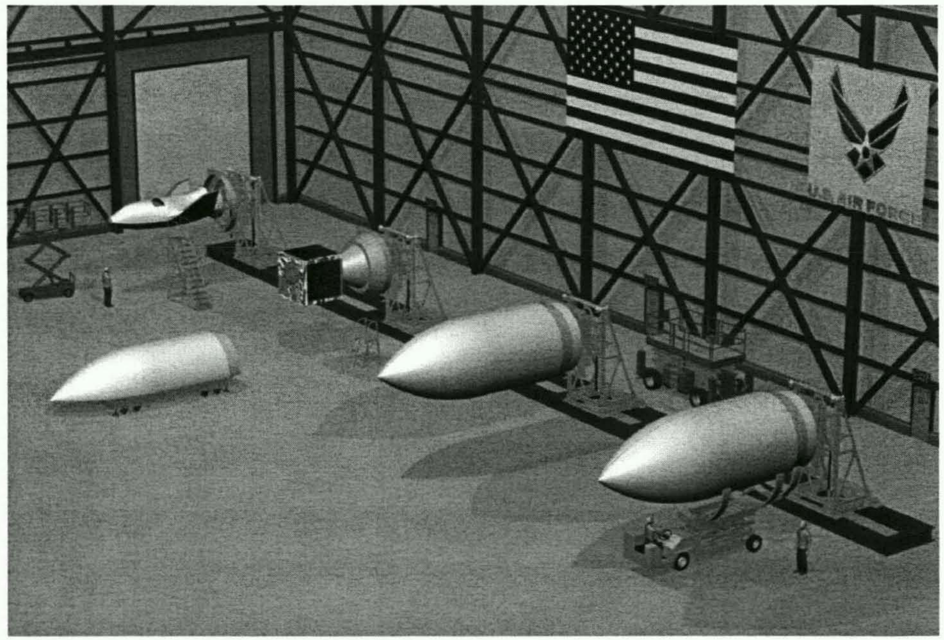
Booster Handling Concept
(Assembly and Transportation)

- 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

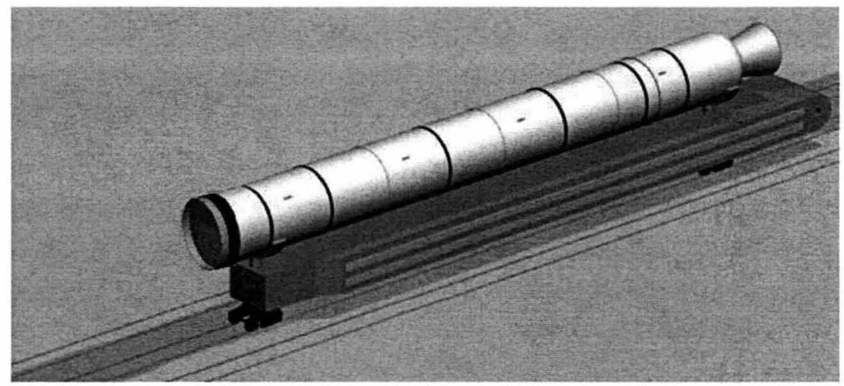
Payload Preparation Concept

- 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)

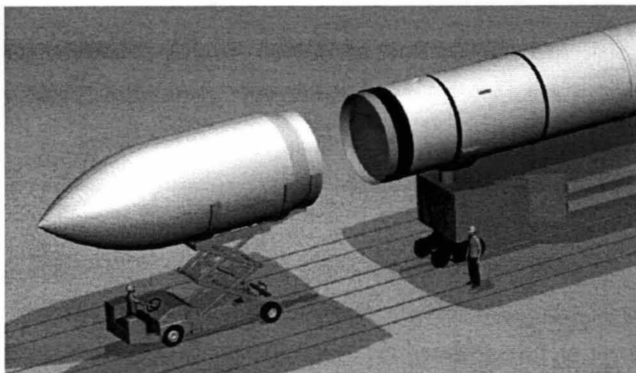
- Upper stage transporter may serve as a manufacturing base and transporter
  - Upper stage may be solid or liquid
  - Upper stage delivered in a "ready for call-up" condition
  - Minimal planned work/services provided on upper stage after delivery
  - Robust, autonomous, self-diagnostic system needed 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

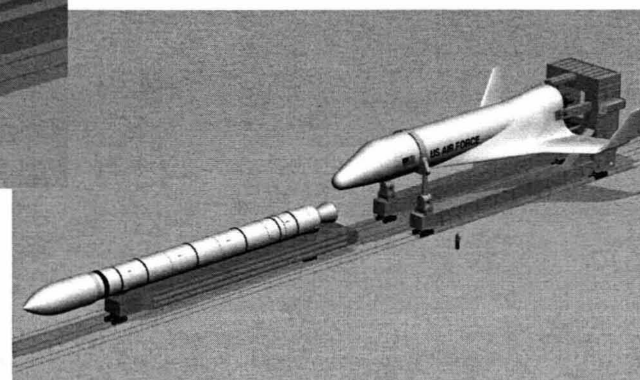
Operational Flow/Systems Concepts
Post Call-up
(L-2 Hours through Launch)

Vehicle Assembly Sequence at Call-Up (L-2 hours)



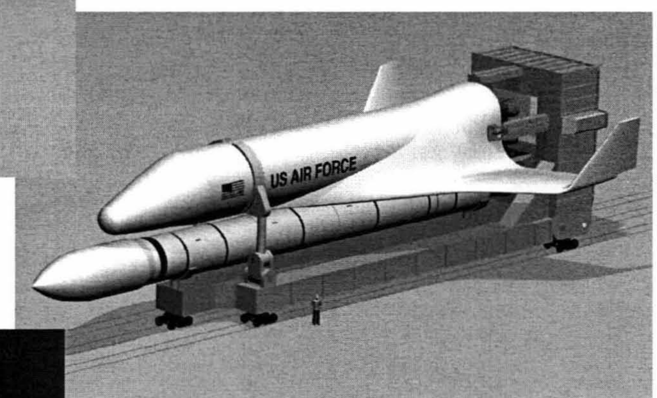
Under-slung upper stage reduces complexity & hazards associated with lifting over booster for mate & access for working at heights

Payload mated to Upper Stage



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

Upper Stage mated to Booster



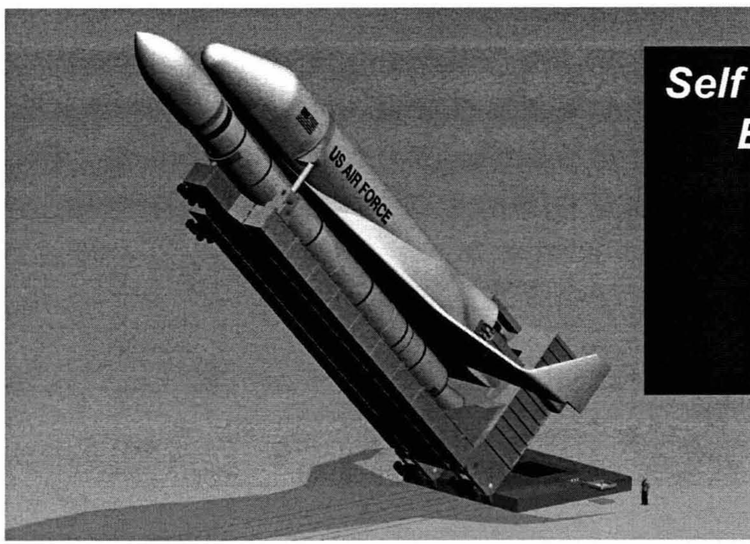
Vehicle travels on rails to pad

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***

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

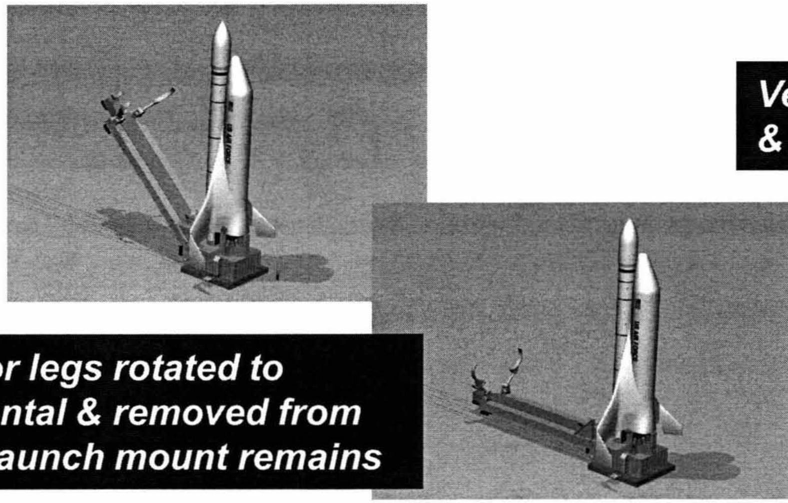


Self aligning aft rise-off umbilical design for Booster and Mission Set (US/PL)

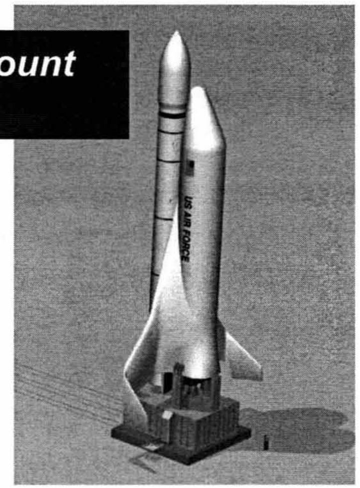
- *Decreases time during call-up due to automated coupling versus manual operations*
- *Launch blast protection decreases pad turnaround time - reduces launch damage risk & exposure to launch plume environment*

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



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



Vehicle on launch mount & ready for launch

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

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

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

Overall Recommendations

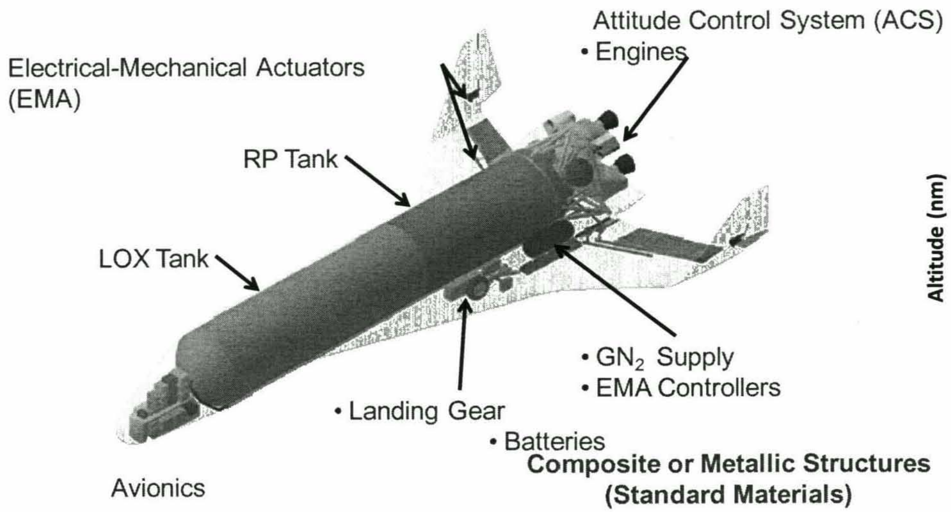
- Include Responsive Operations Expertise Throughout the Flight & Ground System Design Process
- Pursue One-Time Vehicle Certifications versus Flight-by-Flight
- Build Prototypes and Perform Ground Operations Demonstrations
- Conduct Successful Phased Maintenance Demonstrations
- Study Flight Element 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

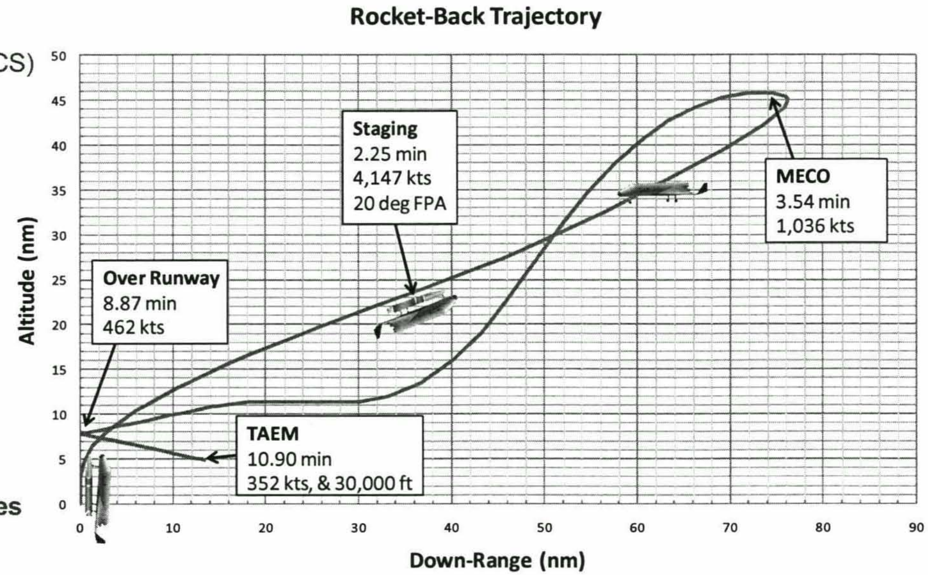
Summary & Conclusions

- 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

RBS Flight Regime





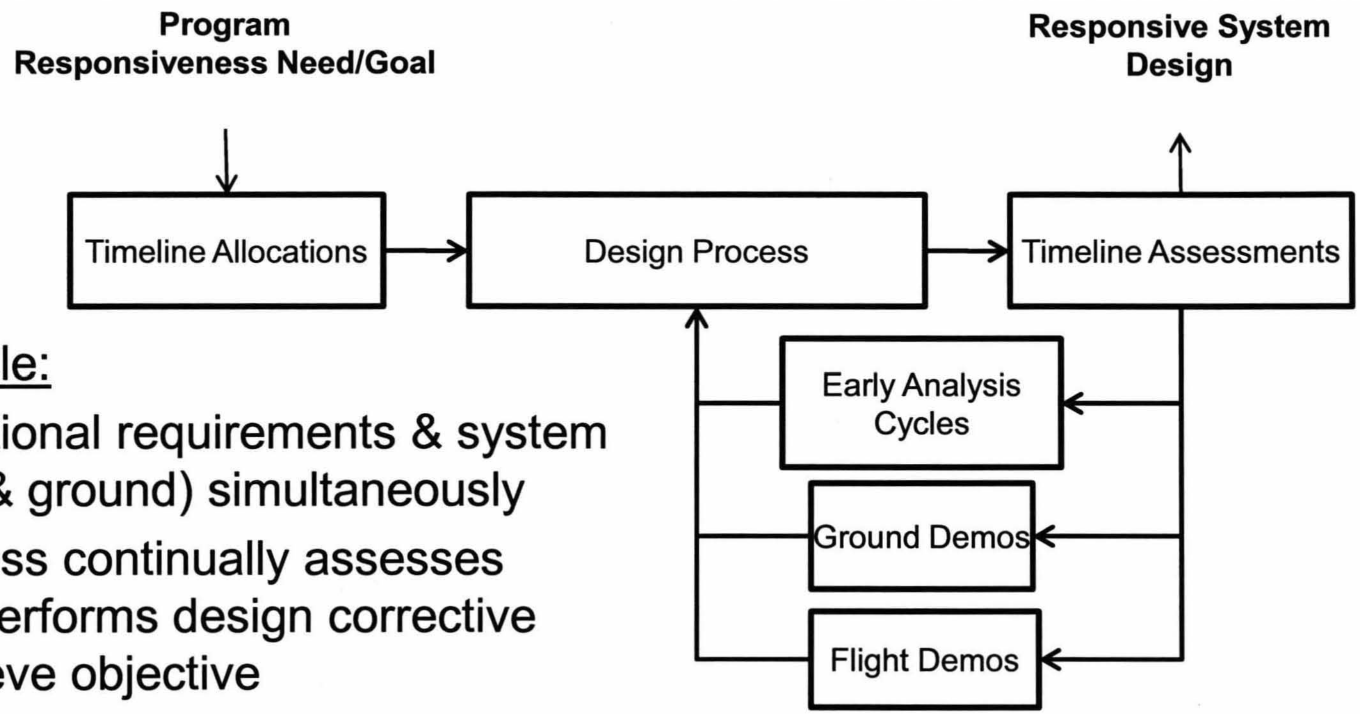
- Booster carries expendable upper stage separated at ~Mach 5
- Booster performs "rocket-back" maneuver to set up glide return to runway in ~12min
- Flight performance trades considered to ensure rapid turnaround
  - Non-traditional approach to ground system design

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

Managing Timelines & Controlling System Responsiveness



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