Complex Rocket Design Considerations

HPR Staging & Air Starting

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Agenda

1. Tripoli Safety Code
2. Technical Considerations
3. Clusters/Air Starts
4. Staging
5. Summary

Tripoli Complex Project Safety Code

1. **Complex High Power Rocket**. A rocket containing multiple rocket motors.
2. **Stability.** The flier shall document the location of the center of pressure and be able to demonstrate the center of gravity.
3. All High Power Rockets shall be flown from the distances set forth in the ***Safe Distance Table*.**

Minimum Safe Distance Table

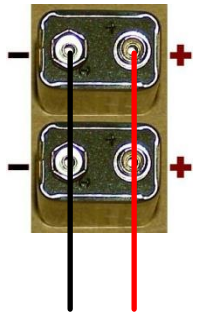
Installed Total Impulse (N-sec)	Equivalent Motor Type	Single Motor (feet/meter)	Complex (feet/meter)
160.01 – 320.00	H	100/30	200/60
320.01 – 640.00	I	100/30	200/60
640.01 – 1,280.00	J	100/30	200/60
1,280.01 – 2,560.00	K	200/60	300/90
2,560.01 – 5,120.00	L	300/90	500/150
5,120.01 – 10,240.00	M	300/150	1,000/300
10,240.01 – 20,480.00	N	1,000/300	1,500/460
20,480.01 – 40,960.00	O	1,500/460	2,000/610
40,960.01 – 889,600.00	P-T	2,000/610	2,500/760

General Technical Considerations

- Motor Selection (Air Start, Cluster or Multi Stage)
  - Propellant Type
    - Avoid Hard Starting Motors (e.g. Greens)!
    - AeroTech
      - Blue Thunder
      - White Lightning
    - Cesaroni
      - Black pellet design permits use of all propellant types (≤54mm)
  - Core Size
    - Smaller is Better (e.g. usually implies easier starting)

General Technical Considerations

- Igniter/E-Match Selection & Wiring (Air Start or Multi Stage)
  - Low Amp, High Temp & Large Gas Production Igniters (E=IR)
    - Commercially made: 1) Oxral (5A), 2) J-Tek (9A - calculated)
    - Commercial kits: 1) Firestar (8.64A), 2) Magnelite (11.25A)
  - Battery Requirements
    - Igniter battery often separate from altimeter
    - Wire igniter batteries in parallel
  - Ignition
    - Support - Wood dowel/Plastic tube/Thread
    - Roughing Core/Pyrogen Coat/Propellant Slivers
    - Research – Head End Ignition
  - Premature Ignition
    - Battery Reversal with specific altimeters
    - RF Transmissions
    - To shunt or not to shunt



9 Volts
2 x Amperage
(1,160 mAh
for Duracell)

Recommendation: Test on motors in sustainers before Air Starting or Staging

Staging

- Why?
- Design Considerations
- Simulation Techniques
- Altimeter Requirements & Programming
- Launch Preparation

Why Stage?

- Additional set of challenges at current cert. level
  - Efficient flights to higher altitudes
  - Multiple flight profiles
  - Multiple deployments
  - Combined and individual stability profiles
  - Combination of multiple motor types
  - Construction challenges
    - Sustainer/Booster coupling
    - Electronics driven ignition

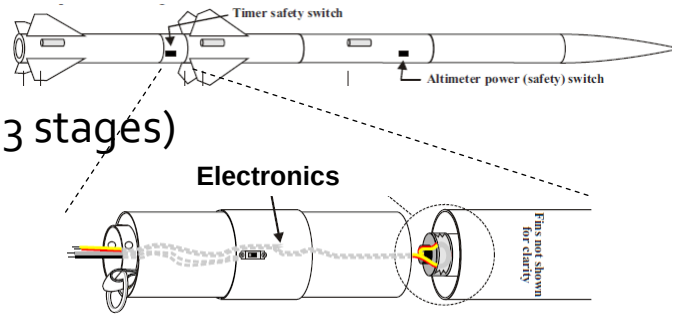
What can go Wrong?

- Failure Modes (non-exhaustive)
  - Stage ignition failure
  - Late stage ignition
  - Coupler malfunction
  - Early, late or no deployment
- Resultant Flight Profile
  - Non-vertical flight (horizontal, loops, powered descent, …)
  - Coupler Failure Issues (Tolerance, Strength, …)
  - Shredding at high velocities
  - Deployment issues
    - Motor ignition after parachute deployment
    - Parachute deployment during motor burn
    - Zippering
    - Stripping parachute
    - Negative Altitude Records (i.e., Core Sampling)
  - Estimated altitude not reached

Staging – Design Considerations

- Inline Staging (Single Sustainer)
  - Vertically stacked boosters and sustainer
  - Each booster is discarded after motor burnout
- Parallel Staging (Single Sustainer)
  - Similar to Air Starting
  - Boosters are externally attached to the sustainer
  - Each booster separates from the sustainer after its motor burns out
- Parasite Staging (Multiple Sustainers)
  - Similar to Air Starting
  - Sustainers are externally attached to the booster
  - Each sustainer separates after booster burn out

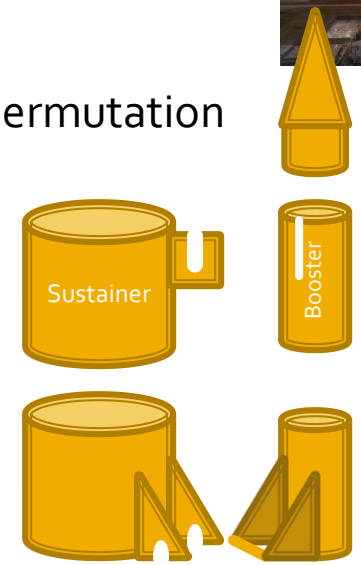
Staging – Configurations



- Inline (e.g. Falcon 9)
  - 2 or more stacked stages (usually not more than 3 stages)
  - Direct ignition is not feasible with APCP motors
- Construction - Interstage Couplers
  - Rod or coupling tube design
  - Electronics may perform the following functions:
    - Ignition of next stage
    - Recovery deployment for prior stage
    - Charge separation of stages
- Separation - Booster
  - Drag, thrust, or charge separation of stages
  - Upper stage ignition delays (coasting to obtain higher altitudes)
    - Consider igniter firing time and time for motor pressurization
    - Coasting too long can result in reduced altitudes, non-vertical flights, …
    - Recommend to start initially with no or short delay after booster burnout
- Static/Dynamic Stability
  - All flight configurations must be stable which includes individual boosters, sustainer, and all design combinations
    - Caveat: slow subsonic boosters could tumble but may cause recovery issues

Staging – Configurations

- Parallel (e.g., Delta II)
  - 2 or more external boosters
  - Boosters ignited with sustainer, before, after, or any permutation
- Construction - Booster Mounting to Sustainer
  - Aft support options
    - Guides with a pivot rod and notched guides on sustainer
    - Explosive bolts
  - Fore support options
    - Slotted booster with guides and pivot rod, sustainer hook
    - Explosive bolts
  - Electronics may perform the following functions:
    - Booster separation and recovery deployment
    - Sustainer ignition and recovery deployment



- Separation - Booster
  - Charge or ejection separation of boosters
  - Separate electronics activation
- Static/Dynamic Stability
  - Again sustainer with all booster flight configurations must be stable
    - Angle boosters through CG when possible

Staging – Configurations

- Parasite (e.g., Space Shuttle kind of)
  - 2 or more sustainers
  - Sustainers ignited after booster burn out
- Construction – Sustainer mounting to booster
  - Aft support option
    - Booster has notched supports for sustainer fins
  - Fore support option
    - Booster fitting for sustainer launch lug or rail guide
  - Electronics may perform the following functions:
    - Sustainer ignition, separation and recovery deployment
    - Booster recovery deployment
- Separation - Sustainer
  - Thrust or charge separation
- Static/Dynamic Stability
  - Again booster with all sustainer flight configurations must be stable

Staging – Simulation Techniques (Rocksim v10.0.0)

- 'Rocket design attributes' tab
  - Set 'Number of stages:' field (default is one)
    - Use one for Parallel or Parasite designs
    - Use two or more for Inline designs
- 'Rocket design components' tab
  - Components
    - Sustainer (Designation 1 - Uppermost stage)
    - Inline
      - Booster (Designation 2 - 1st or 2nd stage)
      - Booster 3 (Designation 3 - 1st stage)
      - Design and build each stage
        - There must be at least one motor mount per stage
    - Parallel & Parasite
      - Add one Pod per Booster/Sustainer, name each booster group, leave ejected during simulations box checked, and set radial position
      - Select Pod and build Booster/Sustainer with a motor mount

Staging – Simulation Techniques (Rocksim v10.0.0)

- Load Motors using 'Prepare to Launch' dialog box 'Engine Selection' tab
  - Inline Simulation
    - Load motors with appropriate Ignition Delay (coast time)
    - Booster motors must have a non-negative numeric Ejection Delay value to stage (Stage Separation Time)
    - All motors will be ignited in stage sequence
  - Parallel Simulation
    - Load Booster & Sustainer motors with appropriate Ejection and Ignition Delays
    - Use identical Ejection Delay times for all motors that are Boosting simultaneously
    - Booster separation occurs based on Ejection Delay (must have a non-negative numeric value)
    - All Ignition Delay times are measured from burnout of the prior stage (e.g., no tie to pods)
  - Parasite Simulation (limited to one sustainer only!)
    - Load Booster and Sustainer motors with appropriate Ejection and Ignition Delays
    - Booster separation occurs based on Ejection Delay (must have a non-negative numeric value)
    - All ignition delay times are measured from prior stage burnout (e.g., no tie to pods)

Staging – Altimeter Requirements

MINIMUM

- Timer(s)
- Pyro channel control based on:
  - Multiple Timed Delays
- Two or more pyro channels

PREFERRED

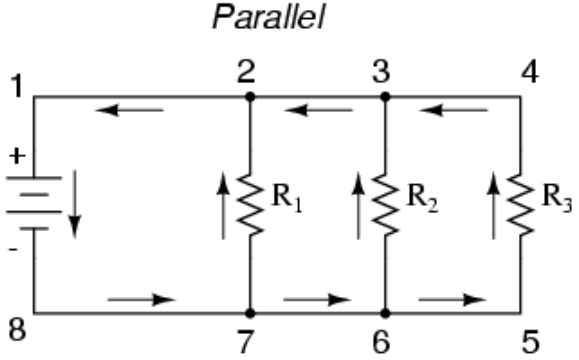
- Accelerometer with timer
- Pyro channel control based on:
  - Deceleration Detection
  - Timed Delay
  - Recognition of Multiple Deceleration Events
- Barometer (for dual deployment of main)
- Two or more pyro channels
- Tilt Detection

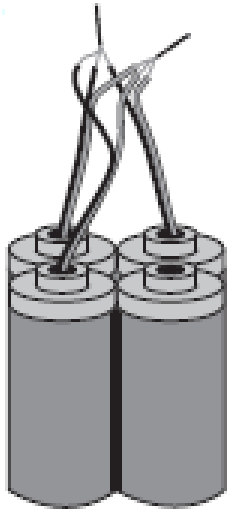
Staging – Altimeter Programming

- Detect Liftoff
- For Each Stage X
  - Do
    - If Barometric Pressure Increasing or Vertical Velocity < 0 or Tilt > 10° then go to Deployment
  - Until Decelerating Vertically And End of Stage X Time Delay
  - Fire Stage X Igniter(s)
- Next Stage
- Deployment
  - Wait Until Apogee Detected And End of Apogee Time Delay
  - Fire Drogue/Main E-Match(es)

Staging – Launch Preparations

- Igniters
  - Always wire in Parallel





  - Consider dipping in pyrogen
- Solid Fuel Motors
  - Roughen top grain core
  - Lightly coat top grain core with pyrogen

Staging Summary

DO'S

- Simulate your flight (all configurations)
- Learn your altimeter and programming alternatives
- Augment igniters and/or motors
- Cant motor mounts through CG (if possible)
- Use robust coupling and separation methods
- Separate batteries for igniters and altimeters as needed

DON'TS

- Use hard starting motors or large core motors in sustainers
- Wire igniters/e-matches in series
- Use high amperage igniters

Cluster/Air Starting

- Why?
- Design Considerations
- Simulation Techniques
- Altimeter Requirements & Programming
- Launch Preparation

Why Cluster or Air Start?

- Cluster
  - Additional set of challenges at current cert. level
    - Igniting multiple motors simultaneously
    - Combining multiple motor types
    - Centering rings & motor mounts
- Air Start
  - All of the above plus
  - Electronics driven ignitions
  - Combine motors and delays for adjustable flight profile

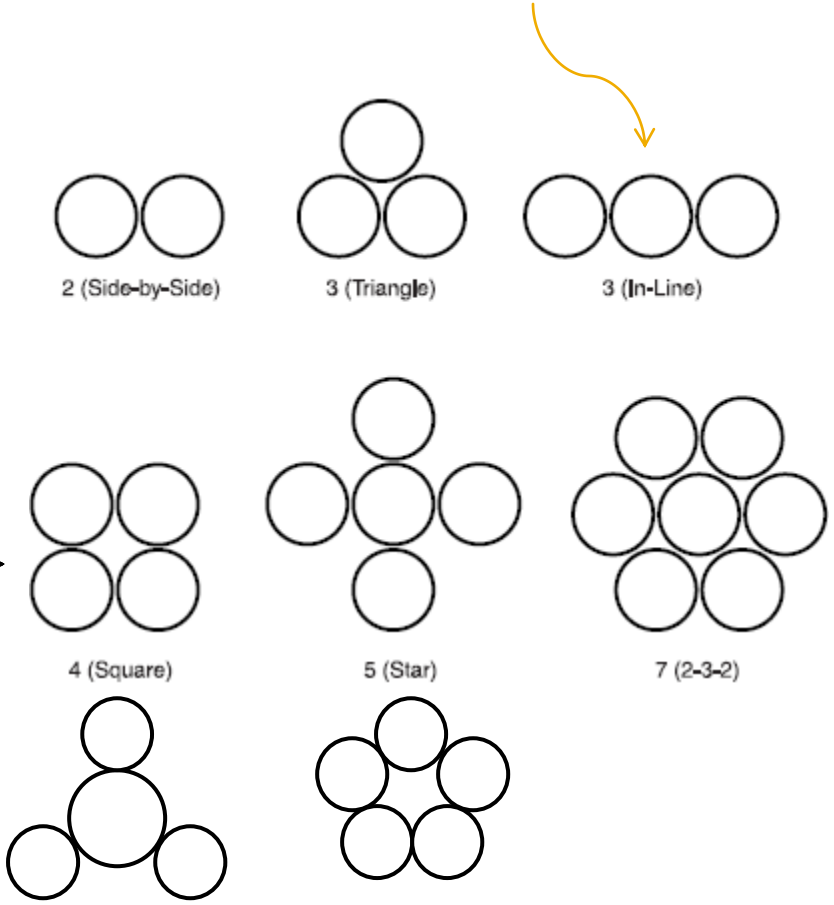
What can go Wrong?

- Asymmetrical Thrust
  - One or more motors do not ignite
  - One or more motors ignite late
- Resultant Flight Profile
  - Non-vertical flight (angled flight, loops, …)
  - Unstable due to inadequate thrust (wind cocking)
  - Deployment issues
    - Late (if motor ejection is used)
    - Zippering
    - Stripping parachute
  - Estimated altitude not reached

Clustering/Air Starting – Design Considerations

- Motor Mounting
  - Alignments
    - Axially Parallel
      - Unstable under Asymmetrical Thrust
    - Angled through Center of Gravity
      - Stable under Asymmetrical Thrust
  - Motor Retention
    - Spacing between mounts
  - Layout Options
    - Geometries must be balanced
    - Heterogeneous mount sizes

Inline geometries will always require the largest diameter airframe



Clustering/Air Starting - Geometries

2) Side by Side – Requires identical motors
   a) Not an option for Air Starting
3) Alternatives
   a) Triangle – Also requires identical motors and not an Air Starting option
   b) Inline – Outside motors must be identical may be used for Air Starting
4) Square – Motors opposite of center (diagonal) must be identical
   a) Up to two motor types may be used
   b) Up to one air start is possible
5) Star – Opposite motors must be identical
   a) Up to three motor types may be used
   b) Up to two air starts are possible
6) Hexagon – Opposite motors must be identical
   a) Six motor configuration (There is also a Rectangle Configuration)
      i. Up to three motor types may be used
      ii. Up to two air starts are possible
   b) Seven motor configuration
      i. Up to four motor types may be used
      ii. Up to three air starts are possible

Clustering/Air Starting – Simulation Techniques (Rocksim v10.0.0)

- Parallel Motor Mounts
  - Add an Inside Tube, name it and mark as motor mount
  - Add other components to the motor mount (engine block, …)
  - If more motor tubes of this type are needed select Cluster
    - For uniform mounts select the appropriate pattern and follow the Wizard instructions
    - For non-uniform mounts select "User tube count & radius" option and follow the Wizard instructions
  - Select a motor mount and add a centering ring
    - The necessary holes are automatically added
    - Copy the centering ring and reposition as many times as needed
- Canted motor mounts cannot be simulated
  - Copy needed motor files
  - Reduce thrust curve using cosine of motor mount angle

Clustering/Air Starting – Simulation Techniques (Rocksim v10.0.0)

- Load Motors using 'Prepare to Launch' dialog box 'Engine Selection' tab
  - Cluster Simulation
    - Load motors with no Ignition Delay
    - All motors will be ignited simultaneously
  - Air Start Simulation
    - Load motors with Ignition Delays (type value then must hit <enter key> - Rocksim quirk)
    - Use identical Ignition Delay times for all motors that are Air Started simultaneously
    - Use different Ignition Delay times for each set of Air Starts
    - All Ignition Delay times are measured from 1st ignition

Air Starting – Altimeter Requirements

MINIMUM

- Timer(s)
- Pyro channel control based on:
  - Multiple Timed Delays
- Two or more pyro channels

PREFERRED

- Accelerometer with timer
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Clustering/Air Starting – Altimeter Programming

- Detect Liftoff
- For Each Air Start X
  - Do
    - If Barometric Pressure Increasing or Vertical Velocity < 0 or Tilt > 10° then go to Deployment
  - Until Decelerating Vertically And End of Air Start X Time Delay
  - Fire Air Start X Igniter(s)
- Next Air Start
- Deployment
  - Wait Until Apogee Detected And End of Apogee Time Delay
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Clustering/Air Starting – Launch Preparations

- Igniters
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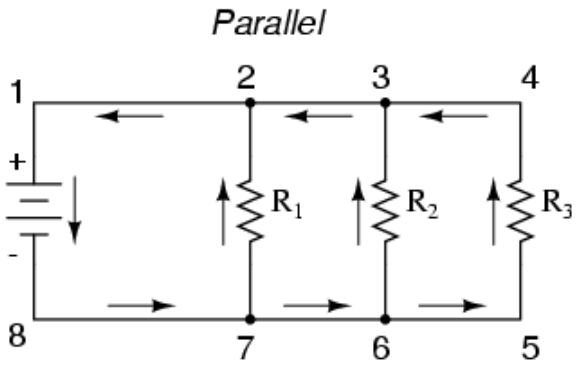

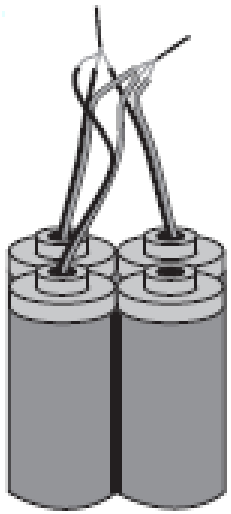

  - Protect wires with Aluminum Tape
  - Consider dipping in pyrogen
- Solid Fuel Motors
  - Roughen top grain core
  - Lightly coat top grain core with pyrogen
- Motor Mounts
  - Cover empty mounts with Aluminum Tape

Clustering/Air Starting Summary

DO'S

- Protect igniter wiring
- Design for motor retention
- Cant motor mounts through CG
- Simulate your flight
- Learn your altimeter and programming alternatives
- Augment igniters and/or motors
- Separate batteries for igniters and altimeters as needed

DON'TS

- Use hard starting motors or large core motors
- Wire igniters/e-matches in series
- Use high amperage igniters

Summary

- Many aspects of Air Starting and Staging are similar
  - Altimeter selection & programming
  - Some design elements
  - Motor and igniter preparation
- Clustering, Air Starting & Staging provide new construction, electronics, and motor challenges at your current certification level
  - Combine all three for even greater challenges