Flight Termination Criteria

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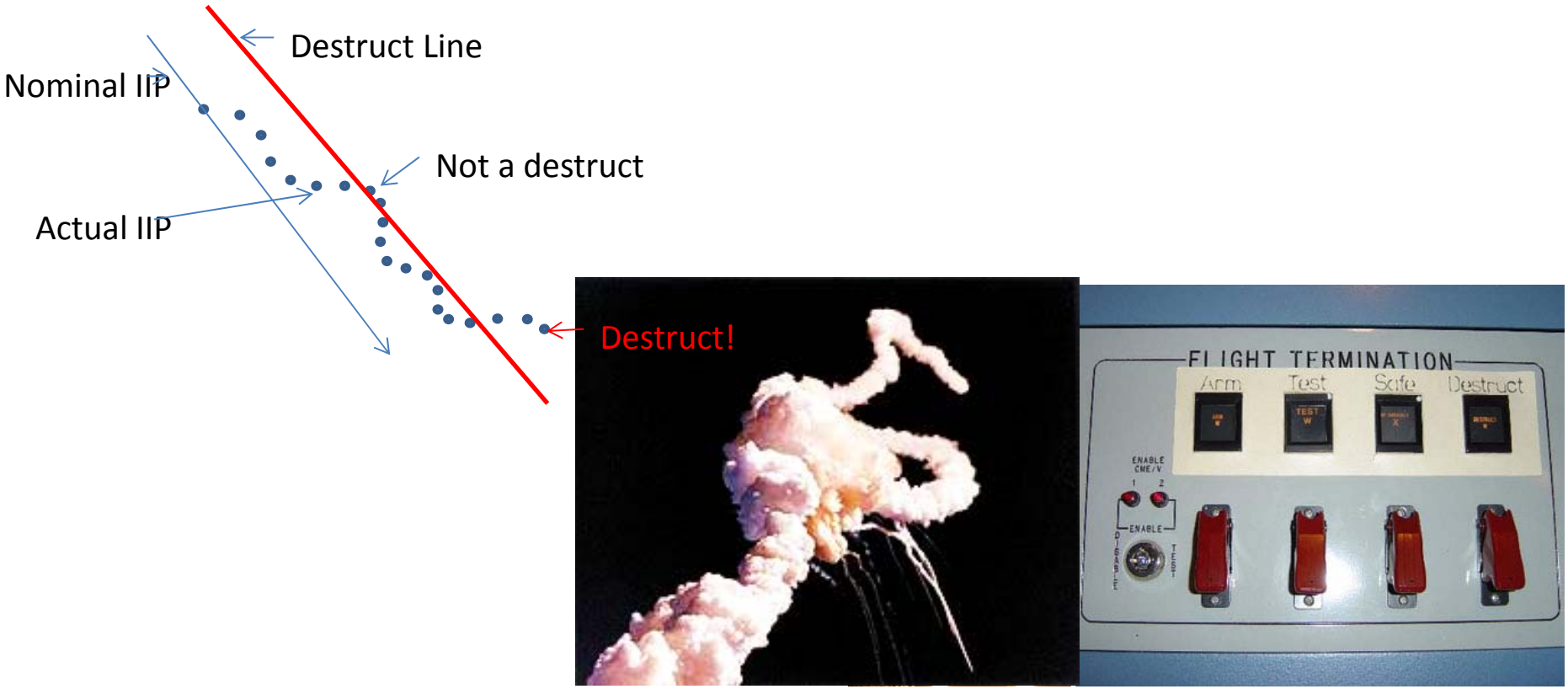
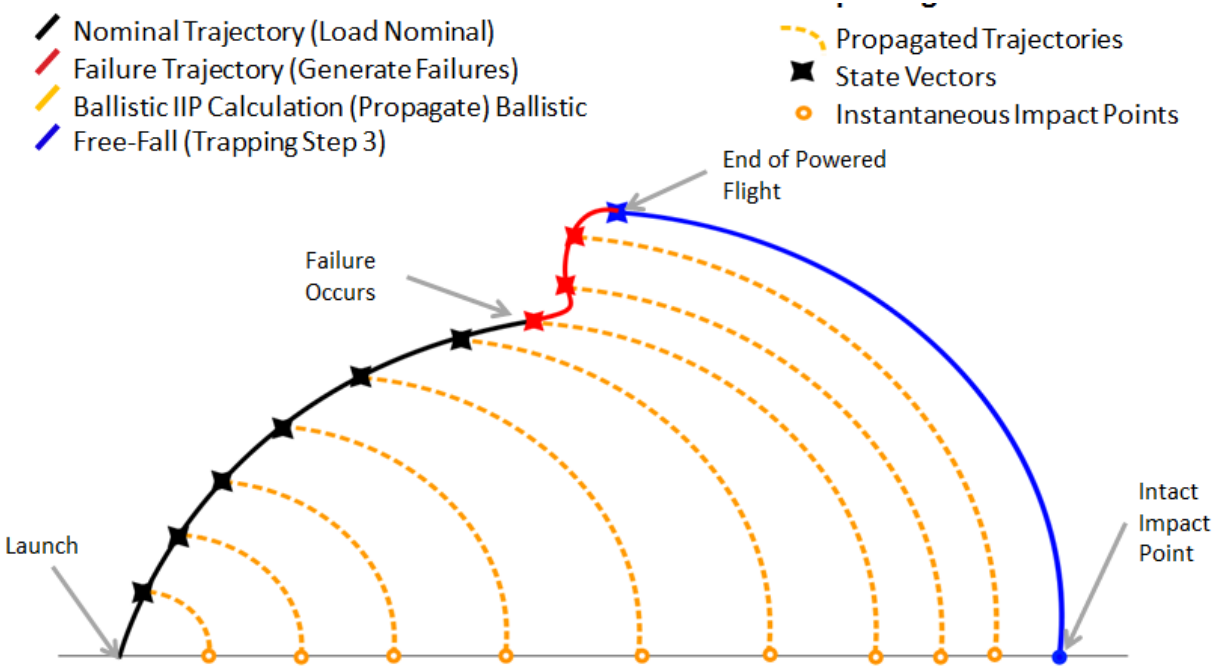


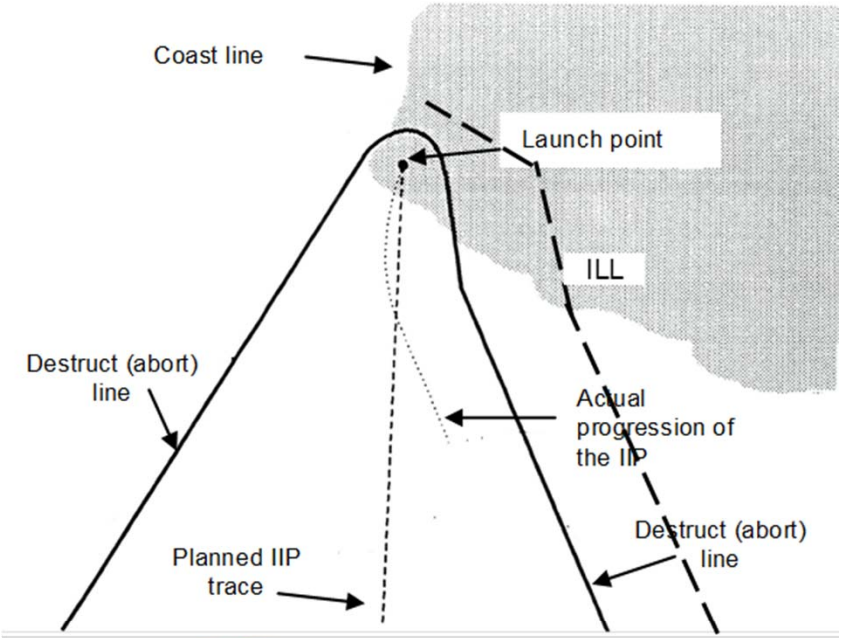
Definition of Terminology



Flight Termination Goals

- Flight termination is the first line of defense against a failing vehicle.
- Must be highly reliable
- Must be effective in protecting against threat to population centers, shipping and aircraft
- Must not **induce** excessive risk when a vehicle flight is terminated
  - Ideally, criteria would balance risk given termination against risk if no termination

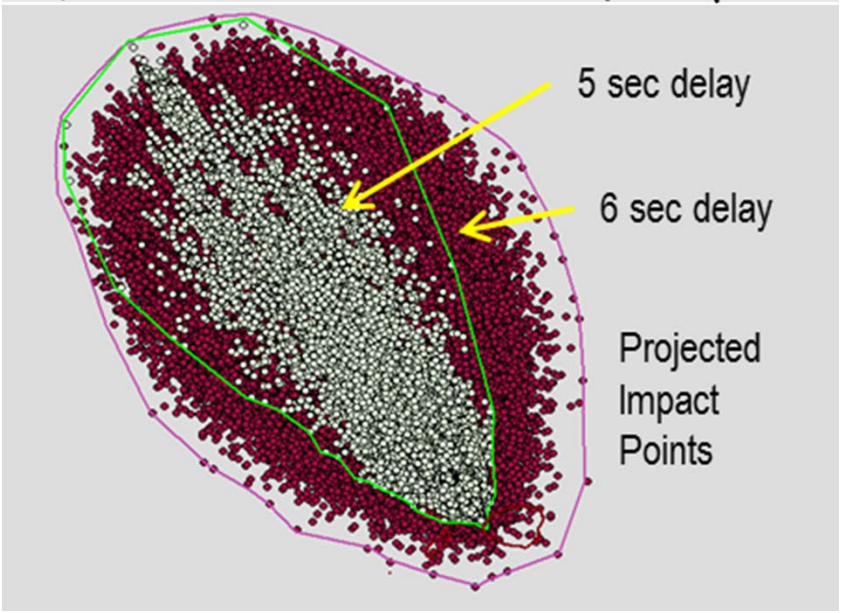
Approaches to Criteria



Define critical regions

Boundary (ILL) about critical region protect against "critical β"

Destruct line to "assure" "critical β" does not cross ILL



Define credible malfunctions

Determine how far IIP can travel in "N" seconds

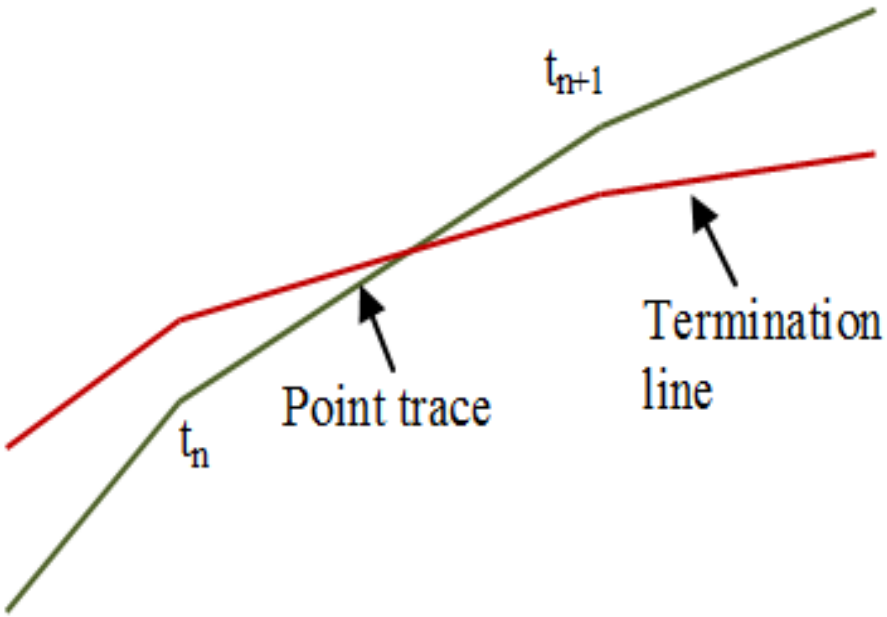
Assess how quickly ("M" seconds) the FSO can detect and terminate a vehicle

Set proposed destruct line at envelope of all failure impact points after "M" seconds

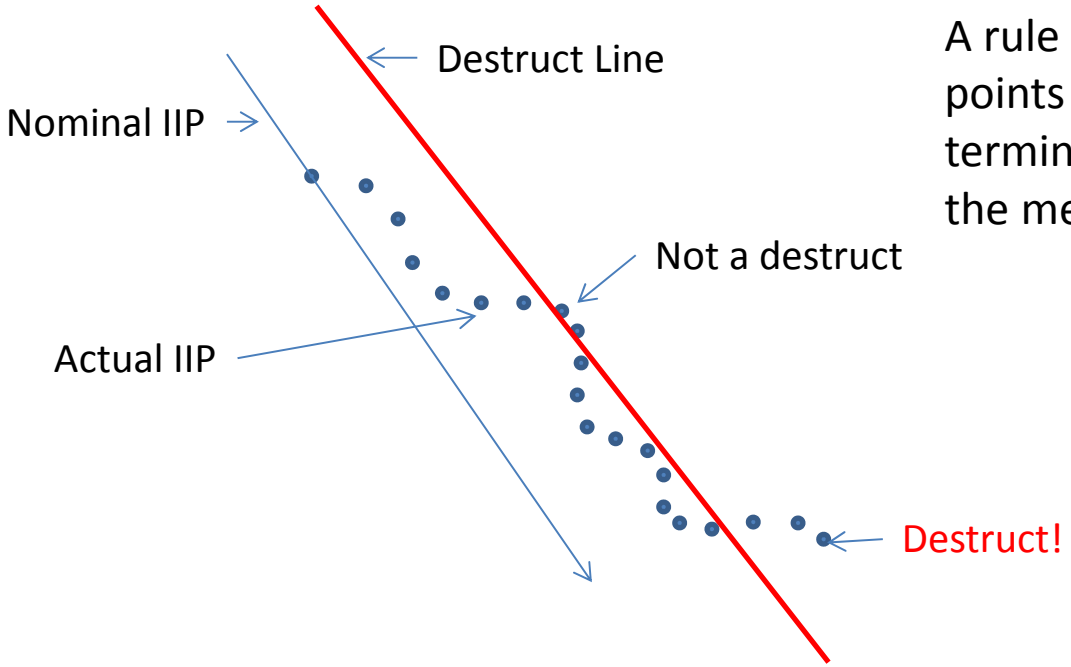
Assess the risk *given termination* from the proposed destruct line

If acceptable, done. Else must adjust destruct line

IIP Base Destruct Line: Simple Crossing

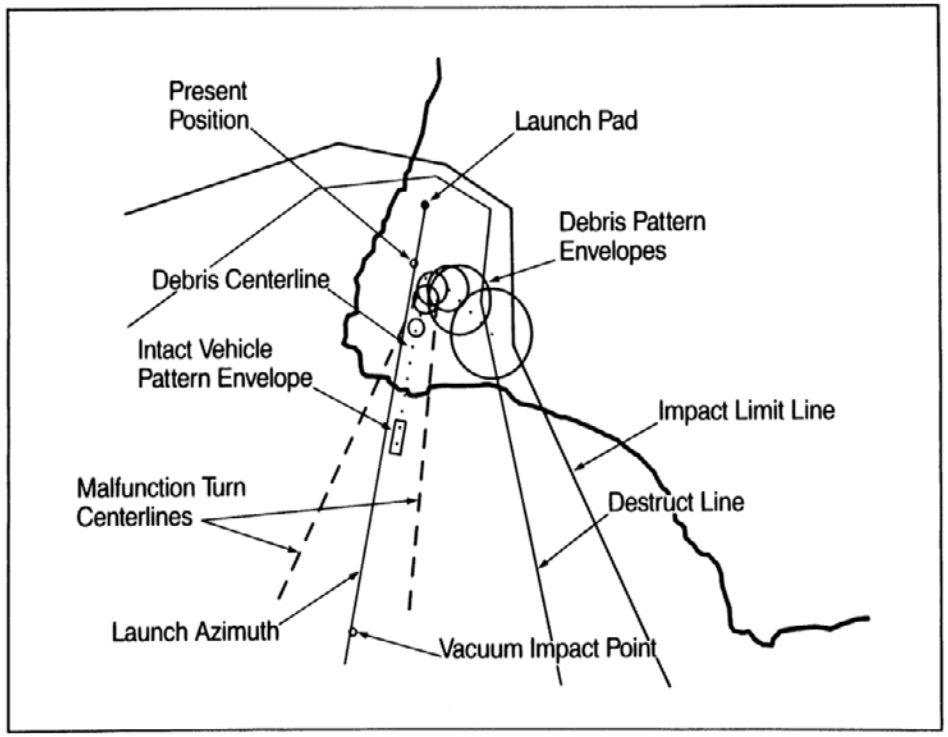


Three Point Rule IIP Based Destruct



A rule requiring “N” (here 3)consecutive points to violate the destruct line before termination protects against “noise” in the measurement system.

Debris Pattern Based Flight Termination Criteria



Although IIP based destruct lines are the most common, debris footprint based footprints have been used. The typical use is to trigger destruct when the pattern crosses an Impact Limit Line.

Footprint based approaches offer the advantage of more directly relating to tolerated risk.

Flight Safety Officers report that it is more difficult to detect a pattern crossing a line than a point crossing a line.

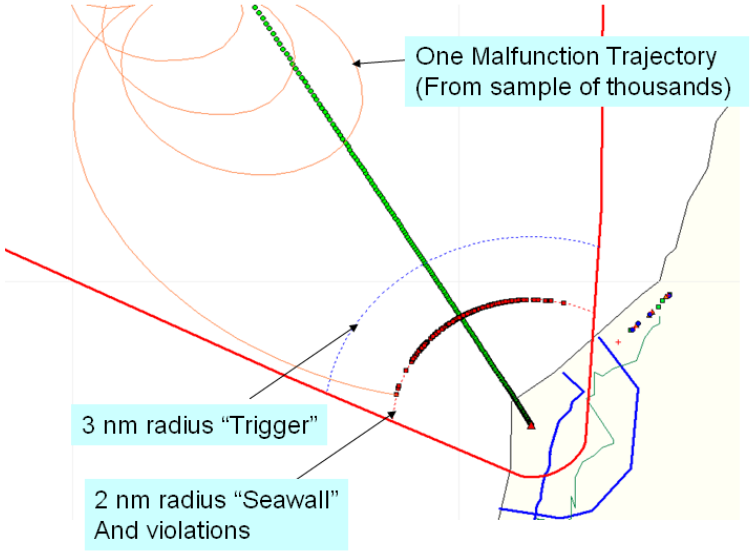
Patterns have been defined based on containment, probability of debris crossing the ILL, and N sigma envelopes.

SPECIAL CONCERNS

> RETROGRADE MOTION

> DIMINISHED THRUST

Protection Against Retrograde IIP Motion: Seawall and Enabling “Trigger”

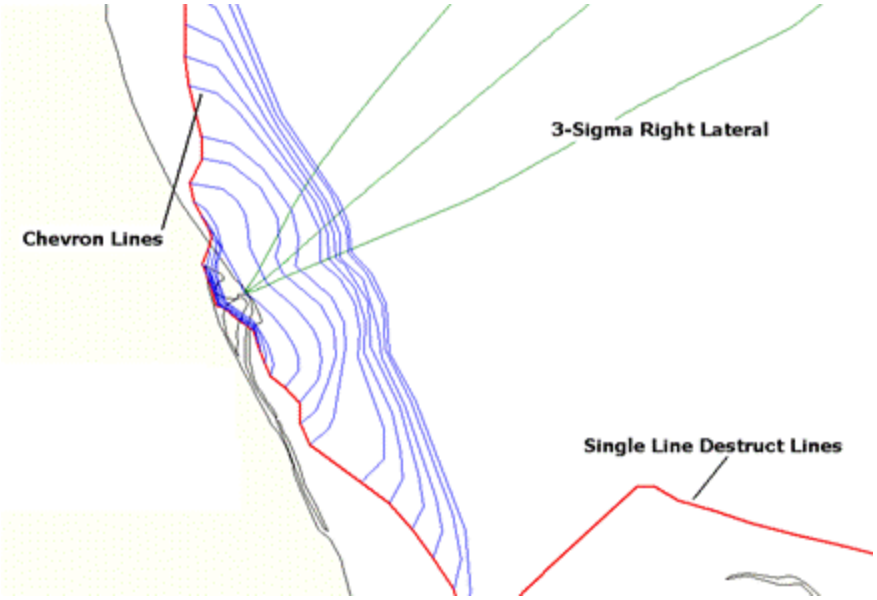


Retrograde IIP motion typically results from a vehicle pitching upward, potentially hazarding the launch site.

A “trigger” radius is often used to assure that the vehicle has progressed sufficiently to have a well defined IIP.

After crossing the “trigger” arc retrograde movement sufficient to cause the IIP to reach the “Seawall” results in destruct.

Flight time dependent destruct lines



An extension of the concept of the seawall in the destruct line that advances downrange as flight time progresses.

This approach protects against degraded thrust in addition to the protection against retrograde IIP movement.

The version illustrated employs moving chevrons to augment fixed left and right destruct lines.

SPECIAL CONCERNS

> TYPE OF FLIGHT TERMINATION SYSTEM

> “BEST” TIME TO TERMINATE

Type of FTS

- Destructive flight termination
  - Pro: Easy to confirm action occurred
  - Con: Costly; May impart large velocities and generate many pieces
  - Comment: Destructive FTS can be designed to reduce imparted velocities and number of pieces
- Thrust Termination
  - Pro: Cheaper; Fewer pieces (possibly one) low or no imparted velocities
  - Con: Potential for explosion on impact; if remains intact and trims nose first, possibility of high consequence impacts

When do you kill a “bad” vehicle?

- Range User / Vehicle Operator: As late as possible; desire to learn from continued operation.
- Range Safety
  - Traditional Answer: As soon as we know it is bad and cannot achieve mission.
  - Modern Answer: It depends on safety objectives and robustness of FTS (next page)

Range Safety Issues:
When to terminate a failed vehicle

- Termination as soon as detected
  - High assurance FTS functions
  - Limits vehicle excursions from nominal flight path
  - May generate more pieces than later termination
  - May impart higher velocities than later termination
  - May have higher altitude at termination than a later termination

Controlling Safety Objectives Affect Right Choice

- Sufficiently robust FTS systems reduce concern about ability to terminate if delayed.
- Objective: Keep debris away from land based population center.
  - Trade off of vehicle excursions vs reduced debris dispersions
- Objective: Protect aircraft / limit size of required NOTAM
  - Higher altitude termination and higher delta v's result in lower fragment densities in debris cloud, potentially smaller NOTAM
  - Smaller number of fragments (from later termination) is a competing effect. Would also reduce fragment densities.
  - Note: Similar considerations for land based population centers when containment is not possible and risk management is required.

Safety Solutions

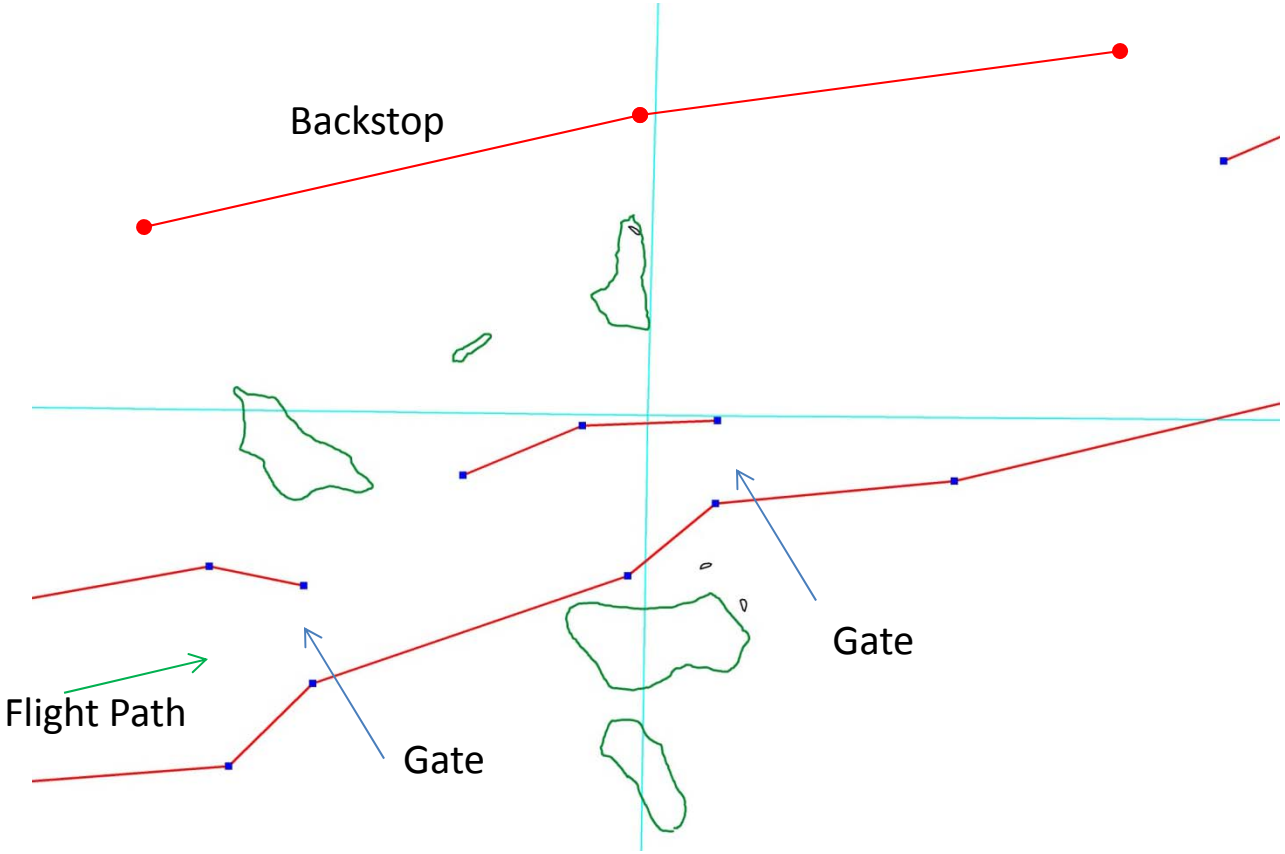
- Assure confidence in FTS performance under proposed solution.
- Risk management will typically require trade-off studies of resulting mission risk and should be augmented with conditional risk analyses.
- When prompt higher altitude termination is preferred solution, additional criteria such as “obviously erratic” vehicle behavior can be used.
- When later termination is desired, widest tolerable IIP based destruct lines can be augmented with altitude based criteria.

SPECIAL CONCERNS

> NAVIGATING AROUND ISLANDS, LIMITS OF COVERAGE

> EARLY FLIGHT TIME CONSIDERATION

Gates with “Backstops” Limit Risks to Islands Near a Flight Path While Protecting Against Unlimited Excursions



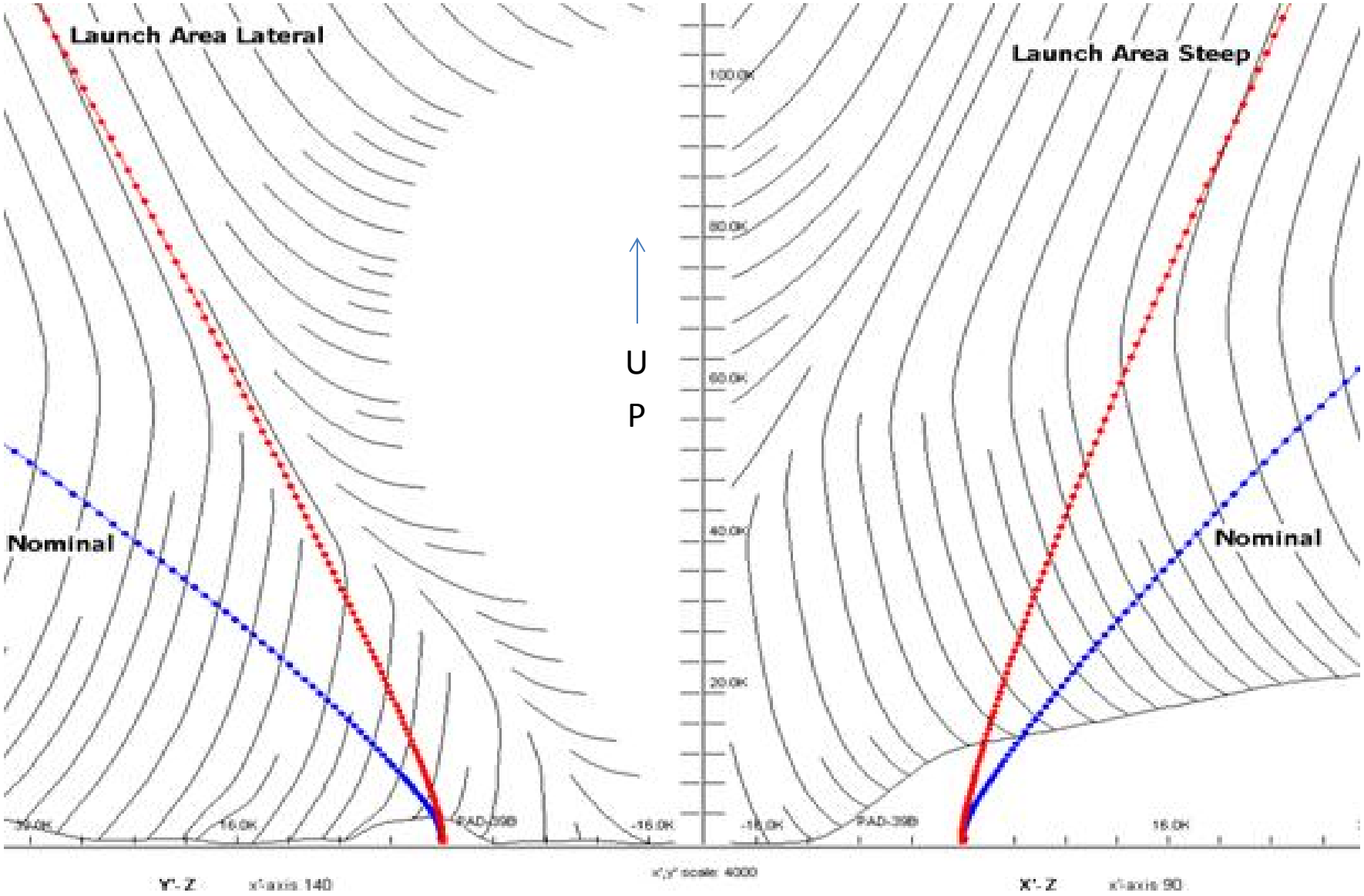
Passage through a gate is only permitted if the vehicle performance is nominal.

A similar concept may be used for space lift vehicles with near orbital velocity vectors prior to overflying large land masses.

Early Flight Considerations

- Objective: Control unsafe vehicles prior to time when IIP is well defined or tracking is reliable.
- Skyscreens: Visual or augmented visual verification vehicle not deviating left or right and programming as intended.
- Vertical Planes: Vertical planes are orthogonal to ILLs. Provides early detection that vehicle threatens to place debris across ILL.

Vertical Planes



SPECIAL CONCERNS

> LIMITED PROCESSING CAPABILITY

> LIMITED VEHICLE CAPABILITY FOR ADDED WEIGHT OR VOLUME

Operational Limitations

- On occasion operational limitations rule our the ability to use impact point based criteria.
- Present position based flight termination criteria (left and right bearings, altitude ceilings and floors as a function of downrange) have been used for some such cases.
- When a program desires a waiver of the FTS requirement for the vehicle or an upper stage they must demonstrate that the risk is *de minimis.*

Summary

- There are a number of different types of criteria that have been developed to limit the risk from a malfunctioning vehicle.
- Proper selection of criteria will involve:
  - Understanding the FTS system reliability, ability to stand failure loads, and debris characteristics that result as a function of flight time.
  - Identifying the governing safety protection objectives and assessing the sensitivity to parameters such as extent of fragmentation, imparted velocities, breakup altitudes, deviations of the vehicle from the nominal.
  - Assuring the conditional risk given flight termination is not excessive.