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Missile Interceptor Simulation Validation

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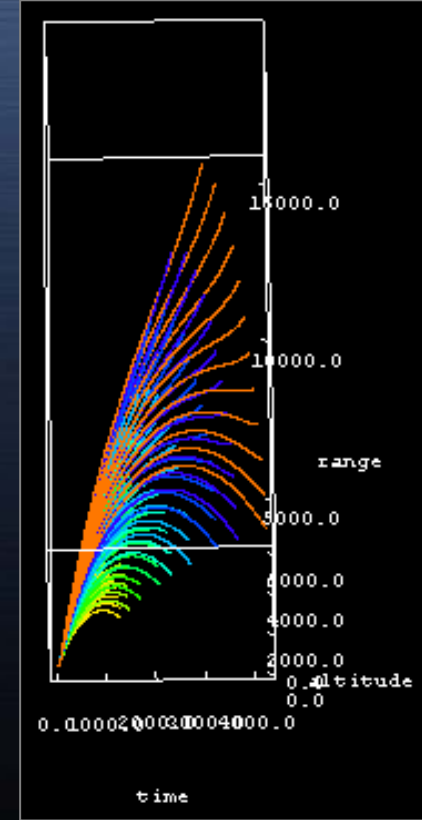
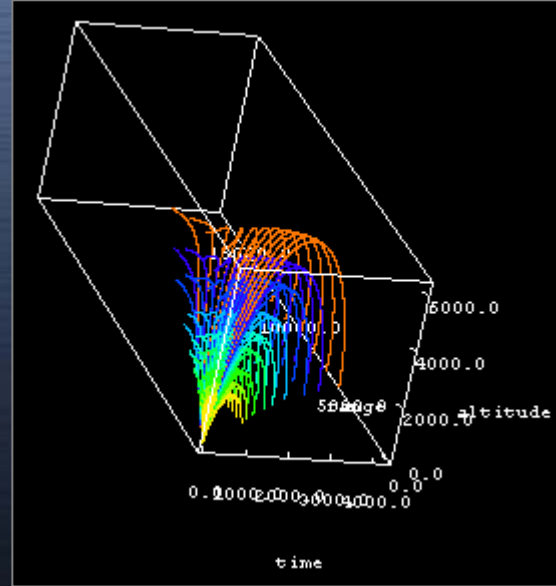
Missile Intercept Problem

- Situation: Hostile entity launches ballistic missile
 - Can it be destroyed in flight by an interceptor?
- Assume:
 - Target is ballistic, cannot maneuver (Keplerian trajectories)
 - Much of flight is exoatmospheric
 - There is a delay in sensing target (battle management)
- Questions:
 - Is the target interceptable by the available interceptor?
 - What trajectory will result in interception?
 - Can I choose my launch time? When can I or when do I have to launch? What is the earliest time I can launch? Latest?

Interceptor Capability

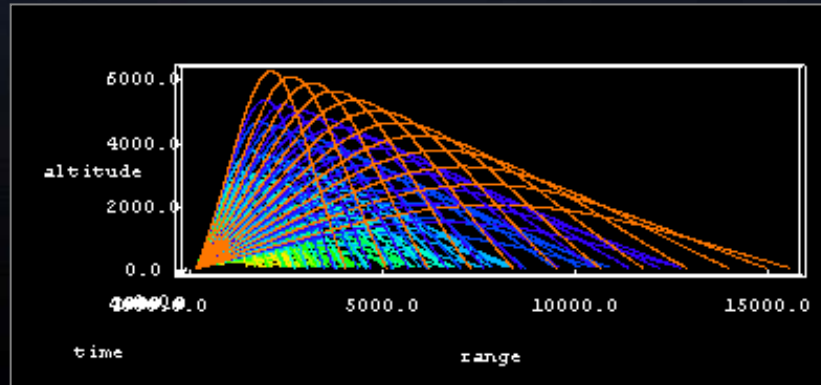
Interceptor Variables

- Launch timing
- Azimuth
- Pitchover
- Energy wasting fraction
(spiral maneuver or early shutdown of motor)



Range

Range



Altitude

Three Views of a Flyout Fan

Time

Simulation Validation Problem

- You run the simulation. What is a good answer?
 - Yes. 1230.5 sec “The lines crossed in the 3D view”
- Can you compare the result to hand calculation?
- You may believe it is right, but can you prove it?
- This interceptor and target worked, but what about others?

Simulation Validation Methods

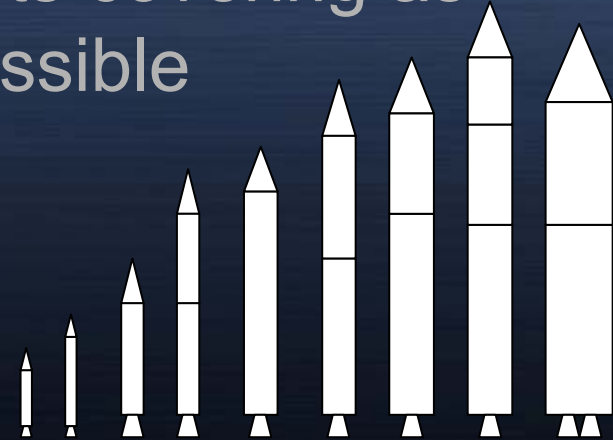
- Compare numeric result to special cases that are easy to solve analytically
- Compare to existing simulations or actual flight test data
- Peer review source code
- Review of results by the community
- Testing of areas known to be prone to mathematical error or complication, especially boundary cases
- Comprehensive, automated testing of use cases
- Testing of similar cases and inspecting results for smoothness

Problems to Watch For

- Numeric equation/algorithm error
- GUI error (of presentation)
- GUI error in translating data from fields into internal variables
- Algorithm logic error; applies wrong test or wrong equation
- Logic processing error; if...then...else error; inverted logic
- Fails to converge during iteration
- Converges to the wrong answer of multiple possible answers
- Spherical trig; angle in the wrong quadrant
- Numeric precision, differences of large numbers, roundoff
- Unknown or unintended algorithmic constraints
- Repeatability, continuity of solutions
- Invalid assumptions
- Sensitive dependence on initial conditions, e.g. chaotic system
- Wrong test applied; test does not meet goal established for it
- Incorrect data entered in test

Validation Test Program

- Create comprehensive suite of tests covering as many foreseeable problems as possible
- Create script to automate testing
- Test:
 - Test, check results, add tests
 - Repeat until many tests and no defects
- Create this briefing, release white paper



Interceptor Simulation Tests

#	Name of Case	Description	Rationale
1	Exact tail chase from equator, heading north	The target is launched from the interceptor's equatorial base location on a trajectory with launch azimuth of zero degrees. Multiple tests are run, each with an increasing interceptor launch delay, until the intercept fails.	Difficult intercept, evaluate smoothness of solutions.
2	Exact tail chase from equator, heading east	The target is launched from the interceptor's equatorial base location on an easterly trajectory. Multiple tests are run, each with an increasing interceptor launch delay, until the intercept fails.	Difficult intercept, comparison to analytic results, evaluate smoothness of solutions.
3	Exact tail chase from equator, heading west	The target is launched from the interceptor's equatorial base location on a westerly trajectory. Multiple tests are run, each with an increasing interceptor launch delay, until the intercept fails.	Difficult intercept, comparison to analytic results, evaluate smoothness of solutions, compare with case 2.
4	Exact tail chase from northern hemisphere latitude, heading southeast	The target is launched from the interceptor's base location north of the equator, on a southeast trajectory. Multiple tests are run, each with an increasing interceptor launch delay, until the intercept fails.	Difficult intercept, checks results of tests 1,2, and 3 with off-equator case, evaluate smoothness of solutions.
5	ICBM tail chase, overflight to east	ICBM target launches from a location 50 km due west of interceptor base. It overflies the base on a trajectory due east.	Difficult intercept, compare with tests 1,2,3, and 4.
6	ICBM tail chase, overflight to west	ICBM target launches from a location 50 km due east of interceptor base. It overflies the base on a trajectory due west.	Difficult intercept, compare with test 5.

30 standard tests covering:

Booster capability

Consistency

Singularities

Spherical trig

Earth rotation effects

Multiple solutions

Standard Tests

7	ICBM tail chase, offset to west	ICBM target launches from a location 50 km north and east of interceptor base. The target launch azimuth is due west.	Difficult intercept, variant of geometry, compare with tests 5 and 6.]
8	ICBM tail chase, polar target	ICBM target launches from North Pole, interceptor base is 50 km south. The target launches along a meridian exactly opposite the longitude of the interceptor base.	Singularity check, compare with tests 5,6, and 7.
9	ICBM tail chase, polar interceptor	ICBM target launches from 50 km south of the North Pole heading due North. Interceptor base is at the North Pole.	Singularity check, compare with test 8.
10	Head-to-head, exact, short range	The target missile's intended target is the interceptor base. The target and interceptor bases are located 100 km apart.	Singularity check.
11	Head-to-head, exact, medium range	The target missile's intended target is the interceptor base. The target and interceptor bases are located 1000 km apart. The target launches from the South Pole.	Singularity check.
12	Pole to pole	The target missile's intended target is the interceptor base. The target launches from the South Pole. The interceptor is at the North Pole.	Singularity check.
13	Head-to-head, north	The target missile's intended target is the 10 km from the interceptor base. The target missile and its target are in the Northern Hemisphere. The interceptor base is in the Southern Hemisphere.	Basic operations.

Characteristics of Tests

Variety of interceptors and targets

Variety of geographic locations

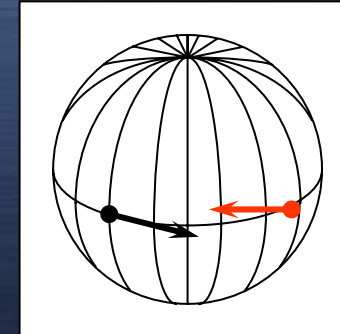
Variety of launch azimuths

Difficult intercepts (tail chase)

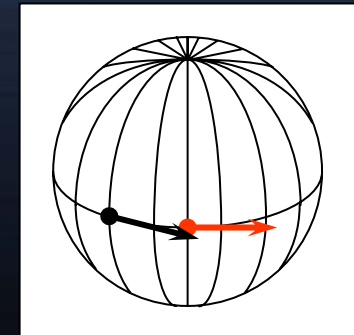
Deliberate flight through poles

More Interceptor Tests

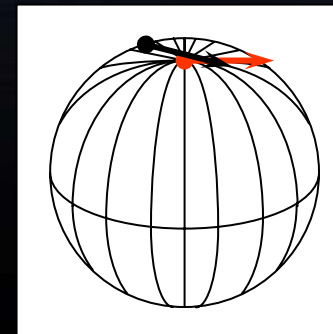
14	Head-to-head, south	The target missile's intended target is 10 km from the interceptor base. Launch and target locations are the same as case 13, except reflected about the equator; i.e. interceptor is in the Northern hemisphere, and target missile and its target are in the Southern Hemisphere.	Compare with test 13, results should be identical.
15	Target headed North, interceptor base to the East	The target is launched from 20 degrees North latitude with azimuth of 0 degrees (due North). The interceptor is east of the target's launch location.	Comprehensive test of intercept geometries.
16	Target headed North, interceptor base to the West	The target is launched from 25 degrees North latitude with azimuth of 0 degrees (due North). The interceptor is West of the target's launch location.	Comprehensive test of intercept geometries.
17	Target headed North, interceptor base to the North	The target is launched from 30 degrees North latitude with azimuth of 0 degrees (due North). The interceptor is North of the target's launch location.	Comprehensive test of intercept geometries.
18	Target headed North, interceptor base to the South	The target is launched from 40 degrees North latitude with azimuth of 0 degrees (due North). The interceptor is South of the target's launch location.	Comprehensive test of intercept geometries.
19	Target headed East, interceptor base to the East	The target is launched from 45 degrees North latitude with azimuth of 90 degrees (due East). The interceptor is East of the target's launch location.	Comprehensive test of intercept geometries.



Head to Head



Tail chase



Polar launches

Conclusion

- Created suite of tests for missile intercept simulations
 - Most stressing cases are tail chases
 - Systematic testing pays off
- Test system white paper expected to be released 1 Aug 04