



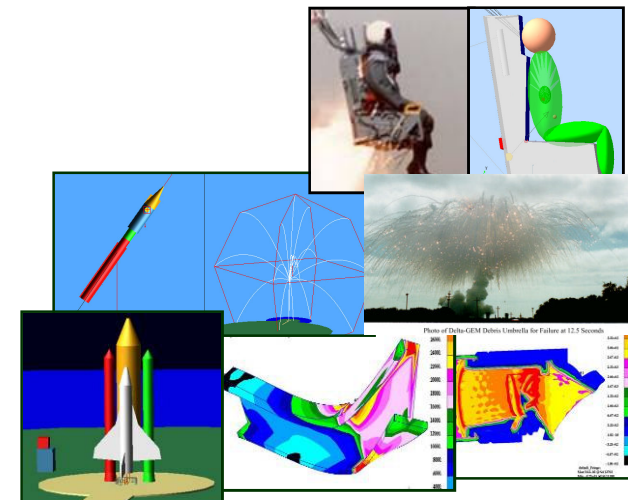
CAPSULE ~100%-FRATRICIDE ENVIRONMENTS

*Estimate of Secondary Effects of the Solid Rocket Booster (SRB)
Destruct Debris Environment on the Constellation Capsule
(Illustrated with the TitanIV-A20 Destruct of Comparable SRBs,
Propellant Mass, and comparable MET of ~40 sec)*

10 July 09

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UNCLASSIFIED

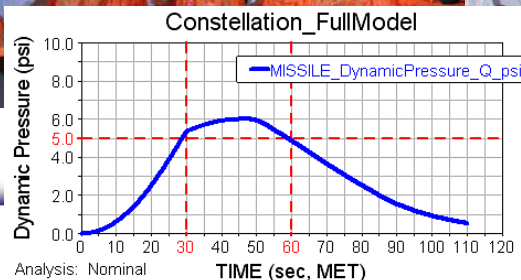
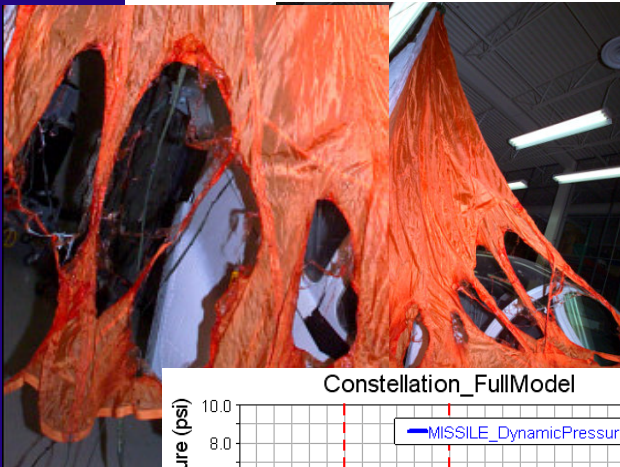
QUICK SUMMARY of RESULTS:

A) FRAG VELOCITY DISTRIBUTION. Propellant fragments expand...

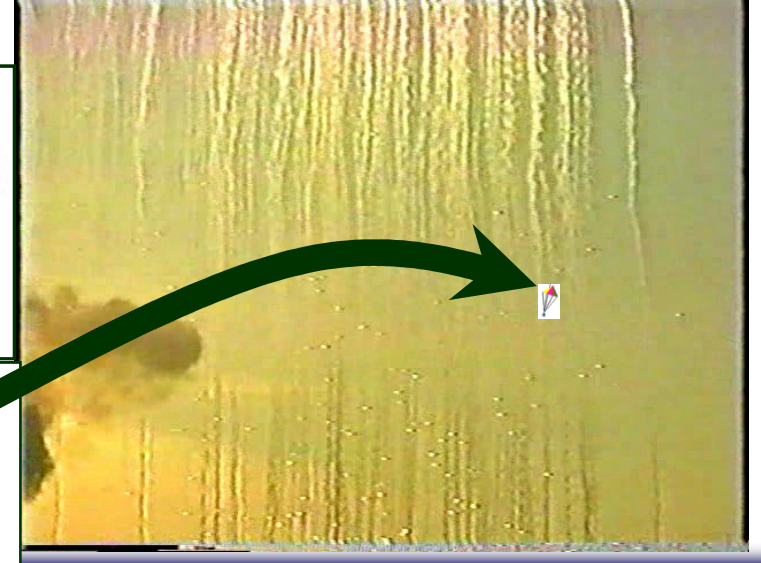
- as a spherical “shell” (i.e. of comparable velocity magnitudes – leaving little distribution of propellant fragments within, or beyond, the “shell”)
- At fairly “tight” ranges, from approximately 300-500 fps (some outliers, each side), with betas from ~20-700 lbm/sqft.
- Mass and count distributions comparable to the “FRAG” program, generated from studies such as the joint NASA/DOE/INSRP Explosion Working Group on the Titan 34D-9 and Challenger 51L.



B) CAPSULE ~100% FRATRICIDE by SECONDARY RADIATIVE WILTING of NYLON CHUTES
 The capsule will not survive an abort between MET's of ~30 and 60 seconds – as the capsule is engulfed until water-impact by solid propellant fragments radiating heat from 4,000F toward the nylon parachute material (with a melt-temperature of ~400F).



CAPSULE
IS
~HERE
 (surrounded throughout
 descent, for aborts
 MET's ~30-60 sec)



PURPOSE:



- a) **Re-Confirm Codes.** Re-confirm predictive codes & values for solid propellant motor fragmentation, comparing results of the late-1980's joint NASA/DOE/INSRP Explosion Working Group (and related) analyses of solid propellant rocket debris (particularly applied to the Titan and NASA SRB's), and verifying that code accuracy continues into the later 1998 Titan A20 destruct at MET=40s.
- b) **Illustrate Capsule Abort Environment.** Illustrate the effect of this solid propellant debris on the Constellation Capsule (particularly the thermal radiative temperature environment of ~4000F while attempting to recover the capsule by deployment of 400F-tolerant nylon parachutes – showing the “probability of hit” is not an indicator of fratricide. A $Ph > 0$ indicates capsule has failed to egress the debris cloud, then thermal induces the Loss of Crew).
- c) **Velocity Distribution.** Suggest values for a “distribution” of predicted uncertainty in debris velocities. Suggest the “credibility” of using velocity variability to justify capsule survival by the variability's “off-max” lowering of a probability of hit (Ph).

APPROACH:

Similar to a complimentary approach in the joint NASA/DOE/INSRP Explosion Working Group study:



- a) Step through frames of the TitanIV-A20
- b) Scale dimensions as best possible
- c) Incrementally calculate velocities of fragments

NOTE: APPLICABILITY OF THE TITAN IVA-20 DESTRUCT is IDEAL:

	<u>Titan-IVA-20 SRB Destruct of</u> <u>12 Aug 1998, off Pad 41,</u> <u>CCAFS</u>	<u>Ares-1 SRB</u>	<i>Comparable Configurations?</i>
Motor Propellant	Composite Solid, PBAN	Composite Solid, PBAN	✓
Propellant Burnrate	0.33 inch per second	0.37 inch per second	✓
Liftoff Propellant	~1.2 Million lbm (2x600klbm)	~1.4 Million lbm	✓
Initial Web Thk	35	39	✓
Chamber Pressure	~700 psi	~700 psi	✓
Nominal Burntime	~120 sec	~120 sec	✓
Destruct Time	~42 sec	30-60 sec	✓
Destruct Method	Longitudinal OD Case Charge	Longitudinal OD Case Charge	✓
Case Diameter	10 ft	12 ft	✓
Case Material	Hardened Steel	Hardened Steel	✓
Case Thickness	~ 0.35 inches	~0.5 inches	✓
Q at 40sec Destruct	~5.9 psi	~5.9 psi	✓



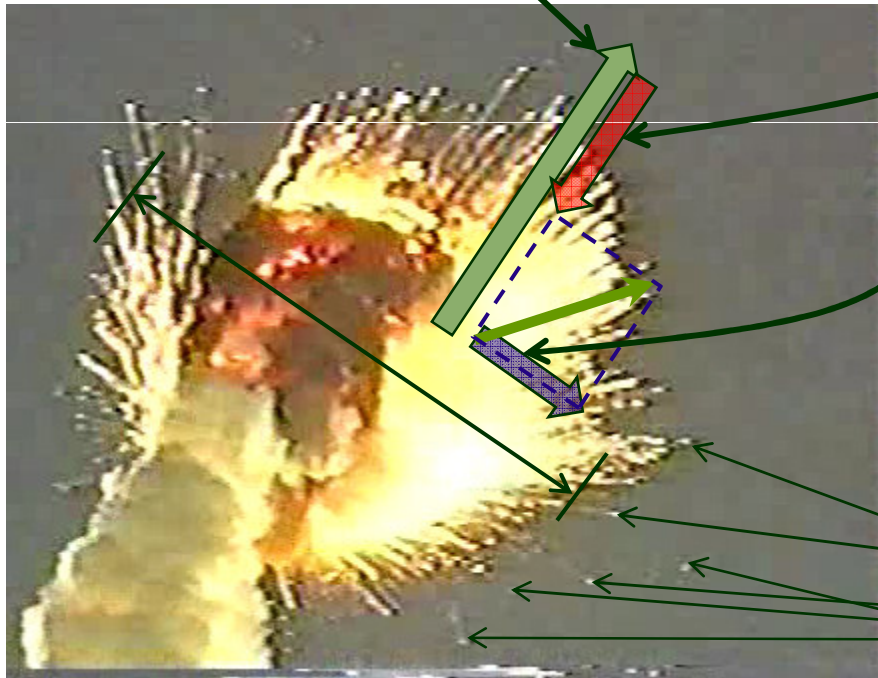
APPROACH:

Use three UNCONSERVATIVE assumptions (i.e. the real “imparted velocity” from the blast will be higher than this estimate)...

- #1) Radial Velocity (only) being tracked
- #2) Neglect the highest-velocity outliers
- #3) Neglect cool (not visible) fragments

Original (“Mothership”) velocity of the propellant

The forward (or aft) component of the “imparted velocity” (from the blast) does NOT grow the “radius” of the debris cloud on the photograph or video - from the camera’s viewpoint



#1) Radial Component (only) of the Imparted Velocity:

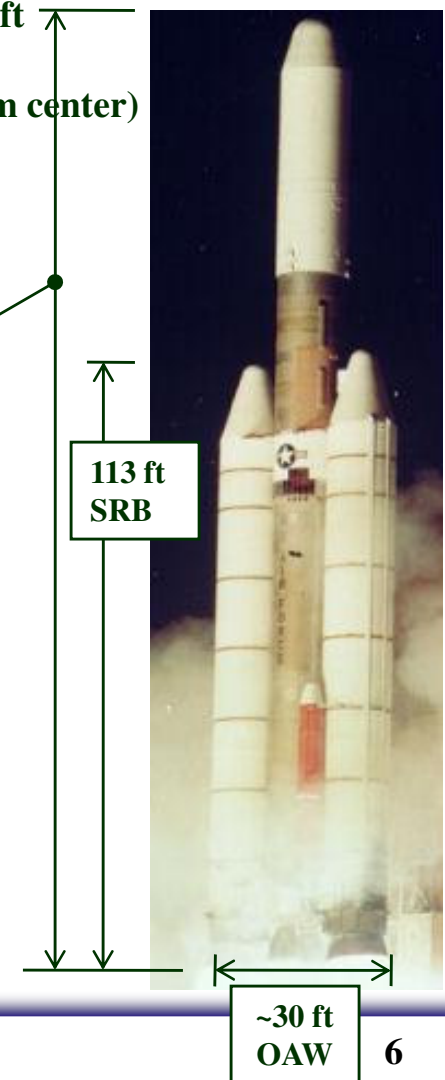
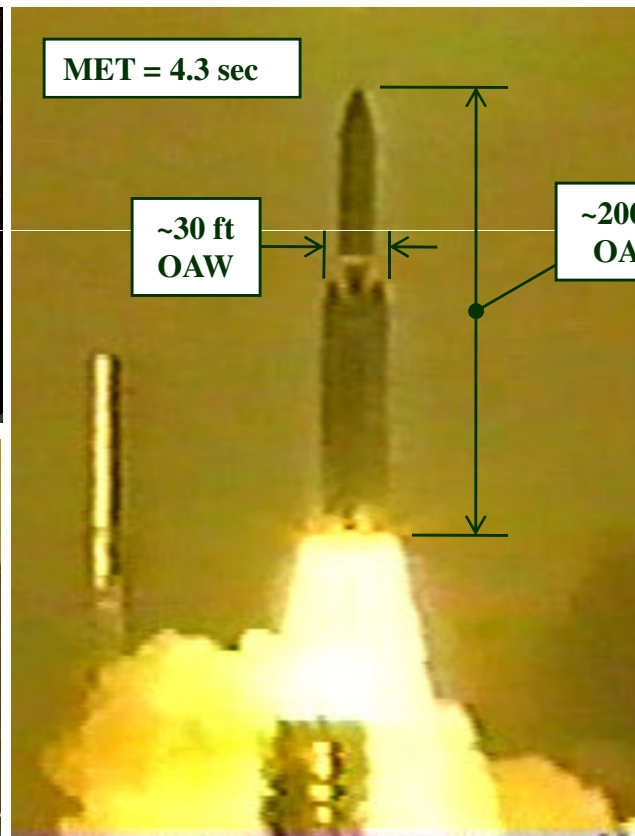
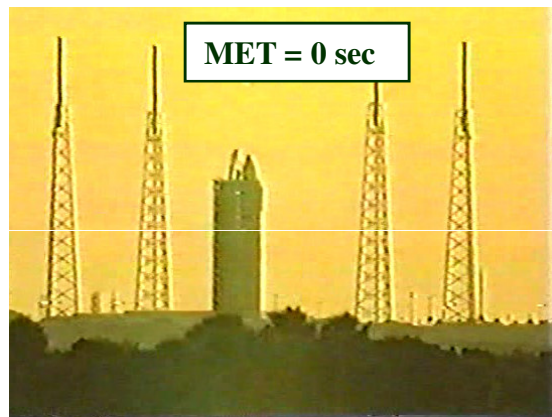
Only reporting the visibly-radial component of the imparted (“blast”) velocity, based only on radial growth of debris cloud. Actual imparted velocity of the fragments could be ~1.5-2x larger, disguised in the original vector direction of the “mothership”, and – in a future event - could direct that fragmentation energy in any direction.

#2 & #3) HIGHEST-VELOCITY OUTLIERS

Neglecting the highest-velocity outliers – which can be the most-lethal, as well as case/hardware that is cool (not glowing) and not seen on the video. Tracking only the bulk, radial growth of the radiant debris cloud.

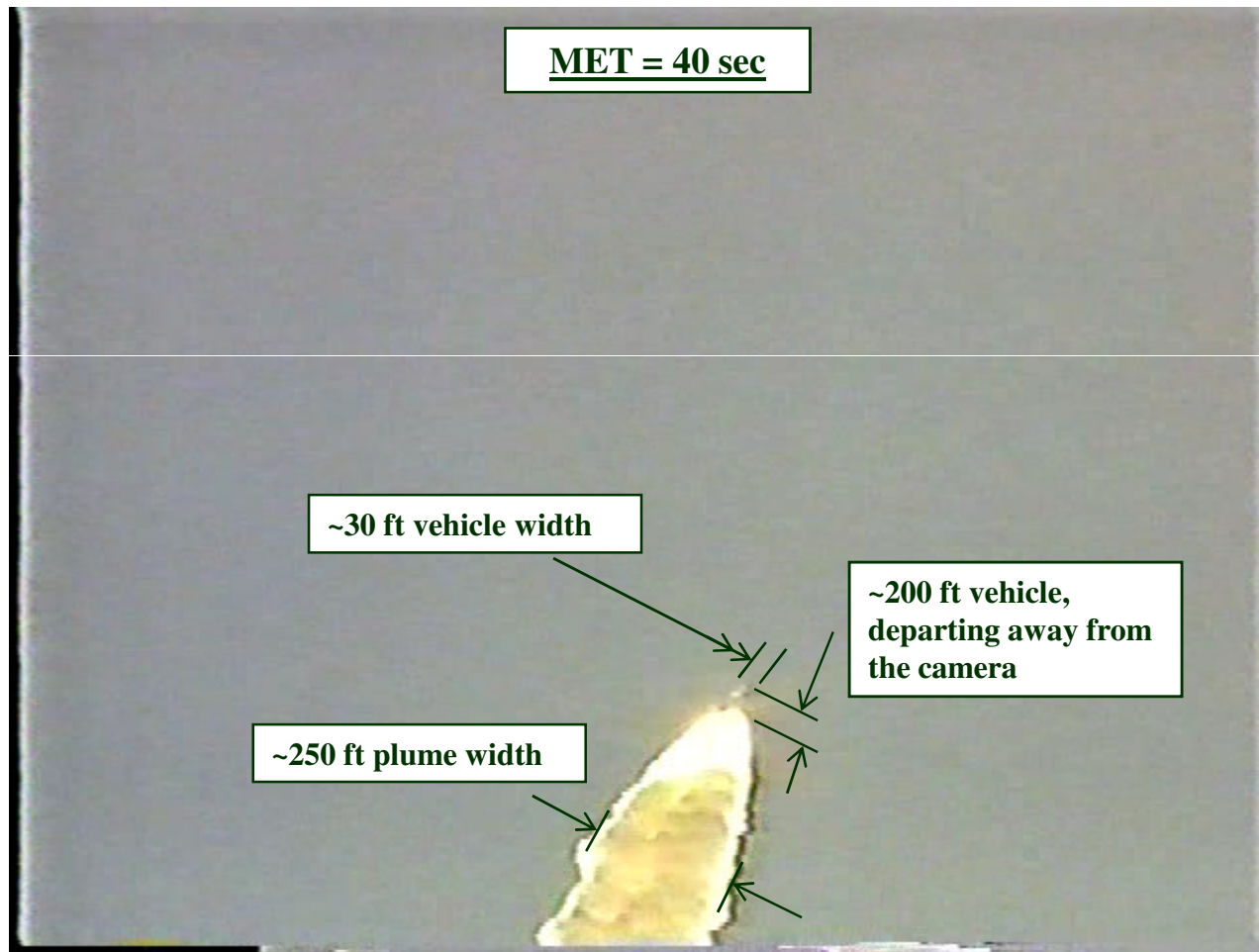
RESULTS: The TitanIV-A20 launch...

- **LAUNCH:** 7:30 am, 12 August 1998, from Pad 41 of Cape Canaveral AFS
- **SRB's:** ~1.2 Million pounds of solid propellant (i.e. SRB's of comparable size and design to Ares-1; ~10 ft diameter, w/ the two containing a total of ~1.2 Million pounds of solid propellant at liftoff, making the hazard somewhat smaller than an Ares-1 SRB).
- **DESTRUCT:** FTS linear shape charge at MET = ~42 seconds, 17k ft-agl, 4.4k ft downrange, 1,000 fps (comparable to the discussed capsule abort hazard).
- **DEBRIS FOOTPRINT:** A diameter of ~3 miles (i.e. a radius of ~7,900 feet from center)



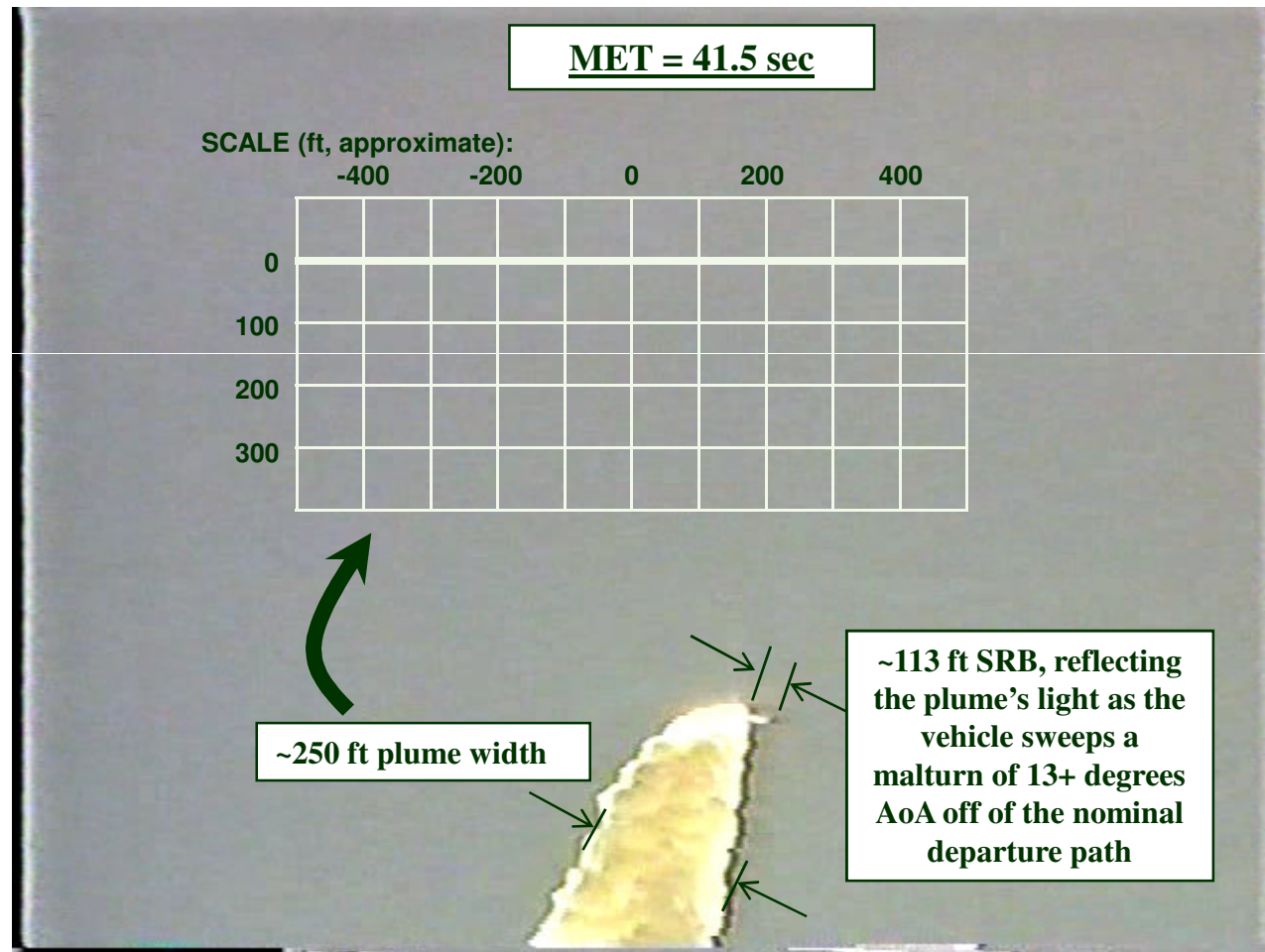
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- DESTRUCT: Comparable to Ares-1 at MET = ~42 sec; at Max Q of ~5.9 psi, ~1000 fps, steel-cased SRB's, totaling ~1.2 Million pounds of solid propellant (i.e. less than one Ares-1 SRB), throwing flaming propellant debris to a radius of ~7,900 feet...



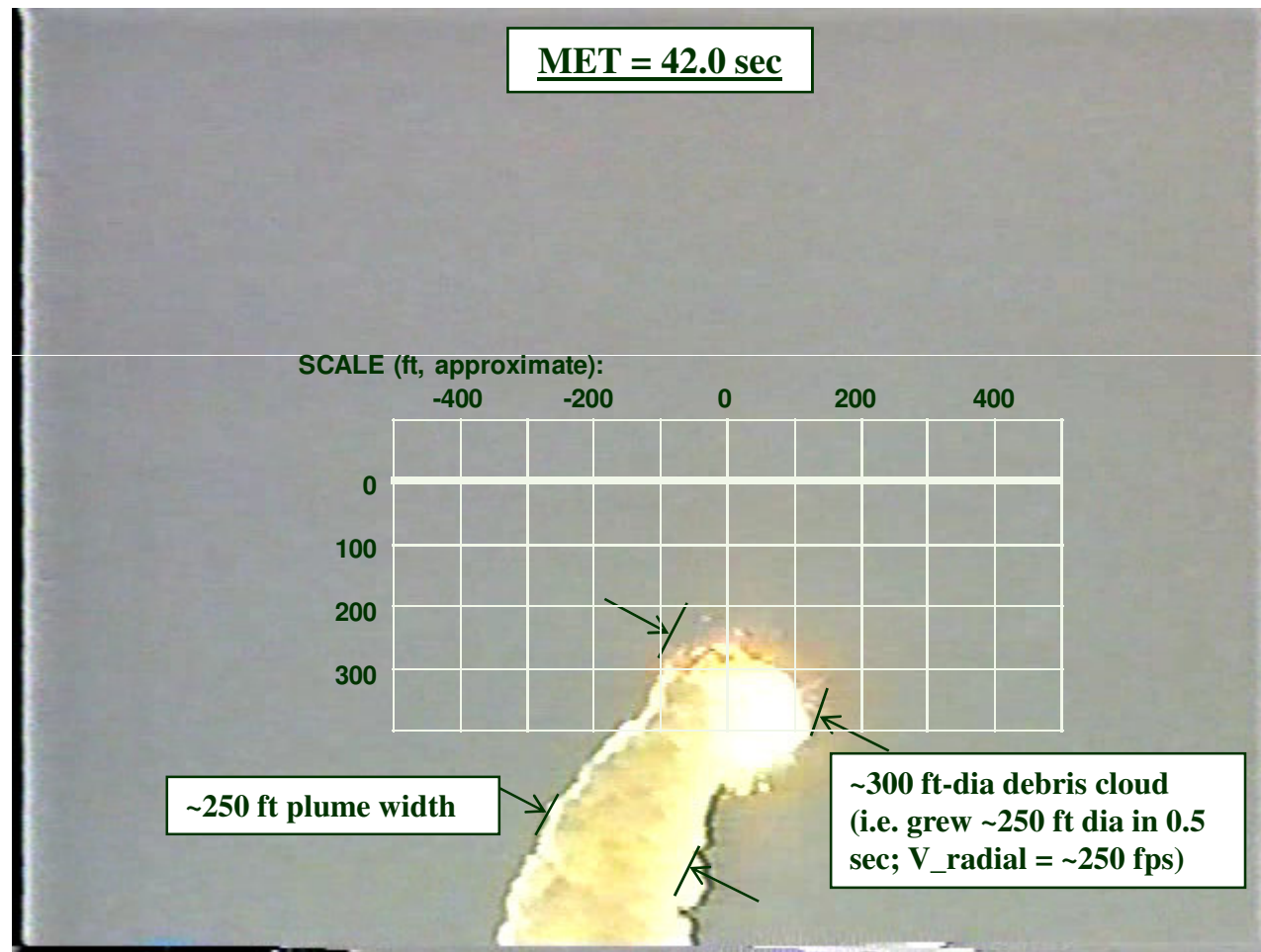
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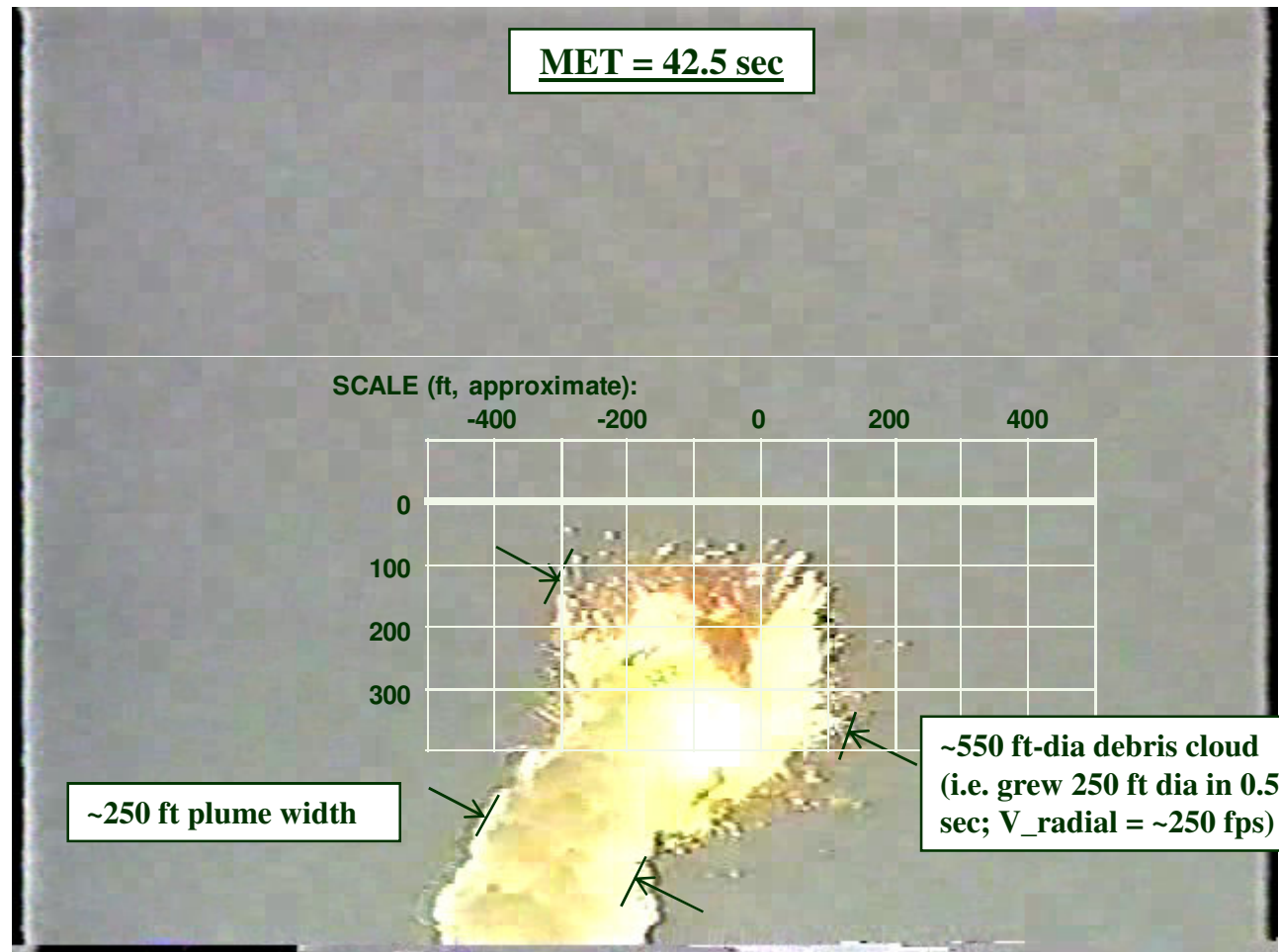
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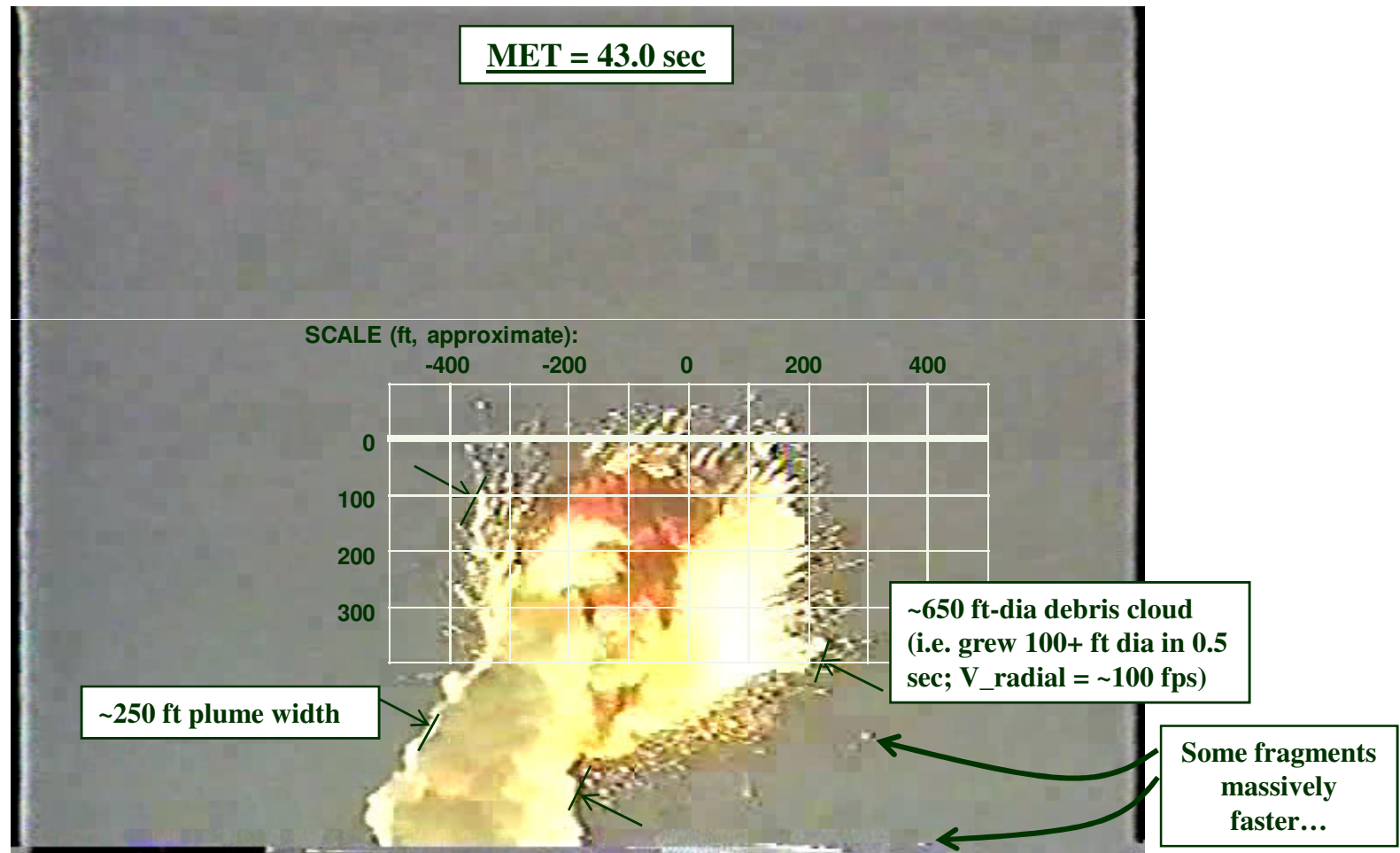
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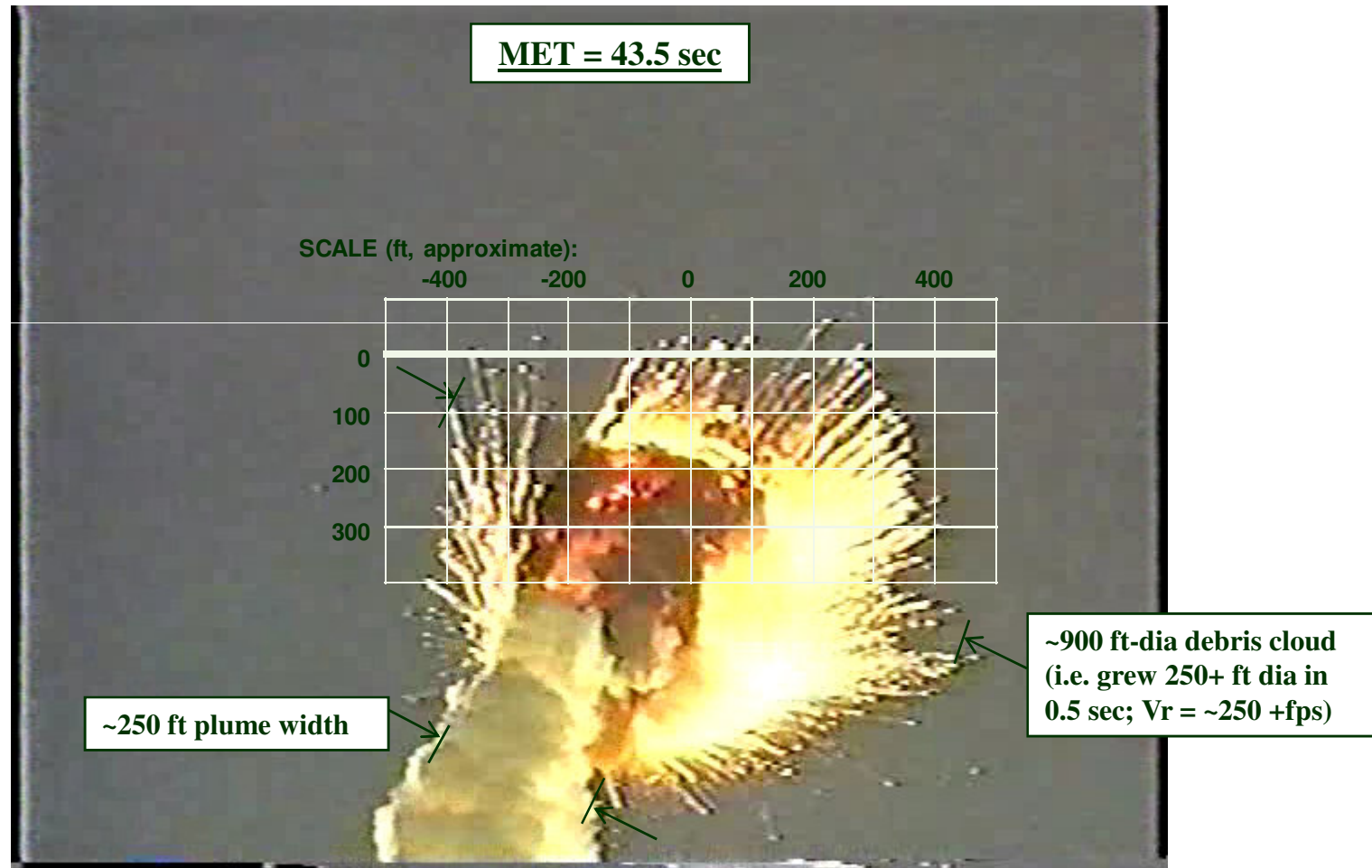
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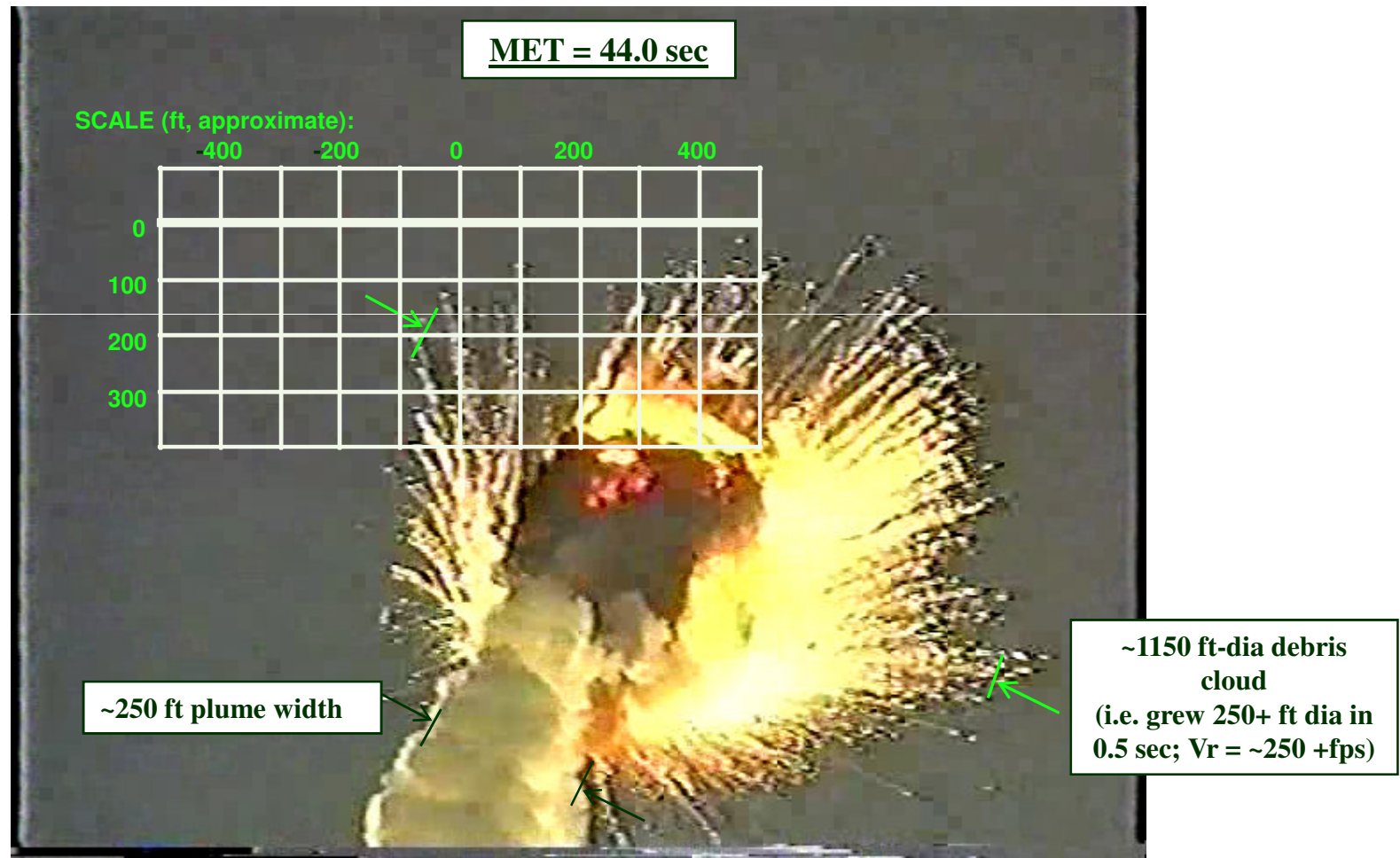
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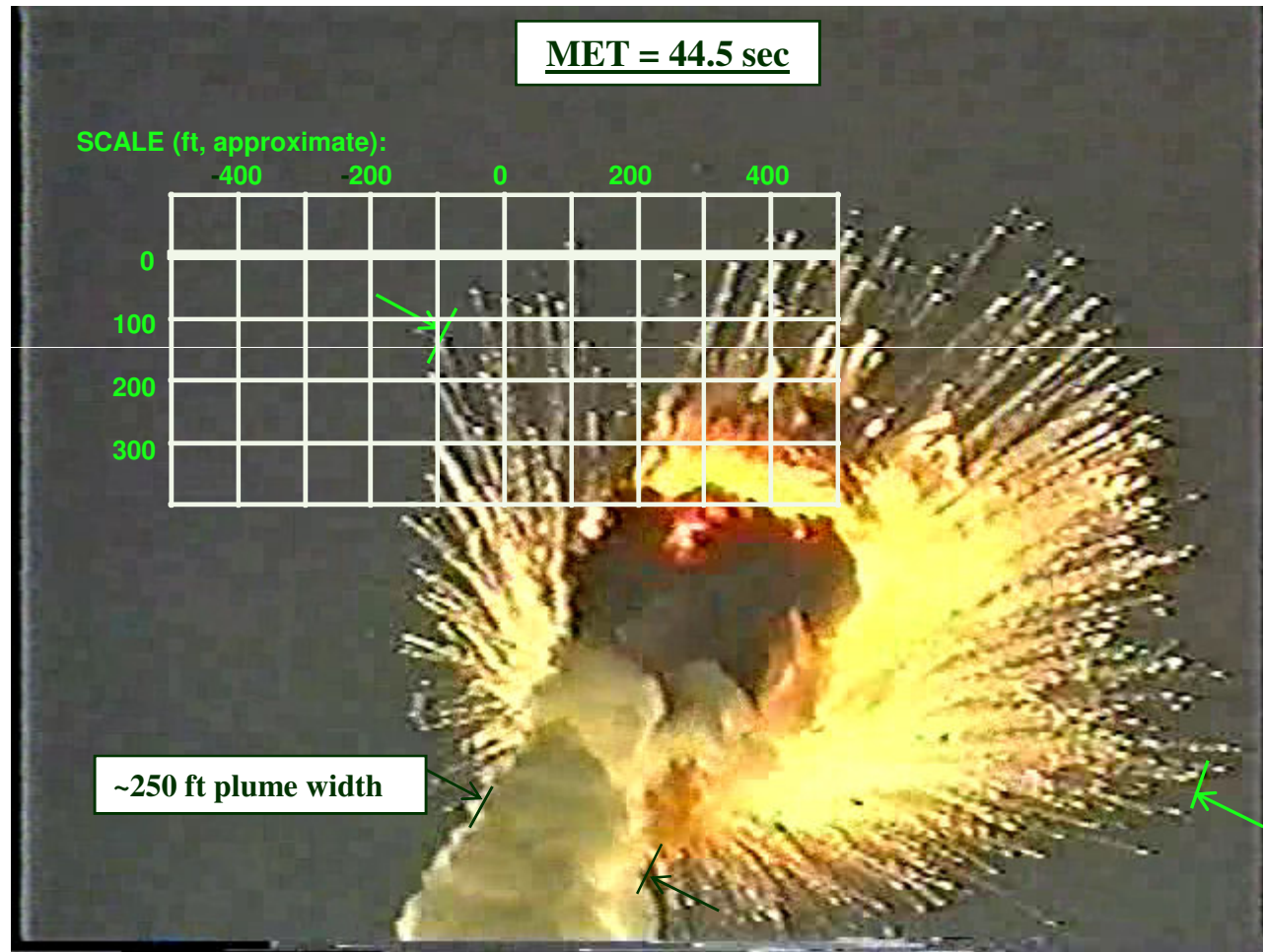
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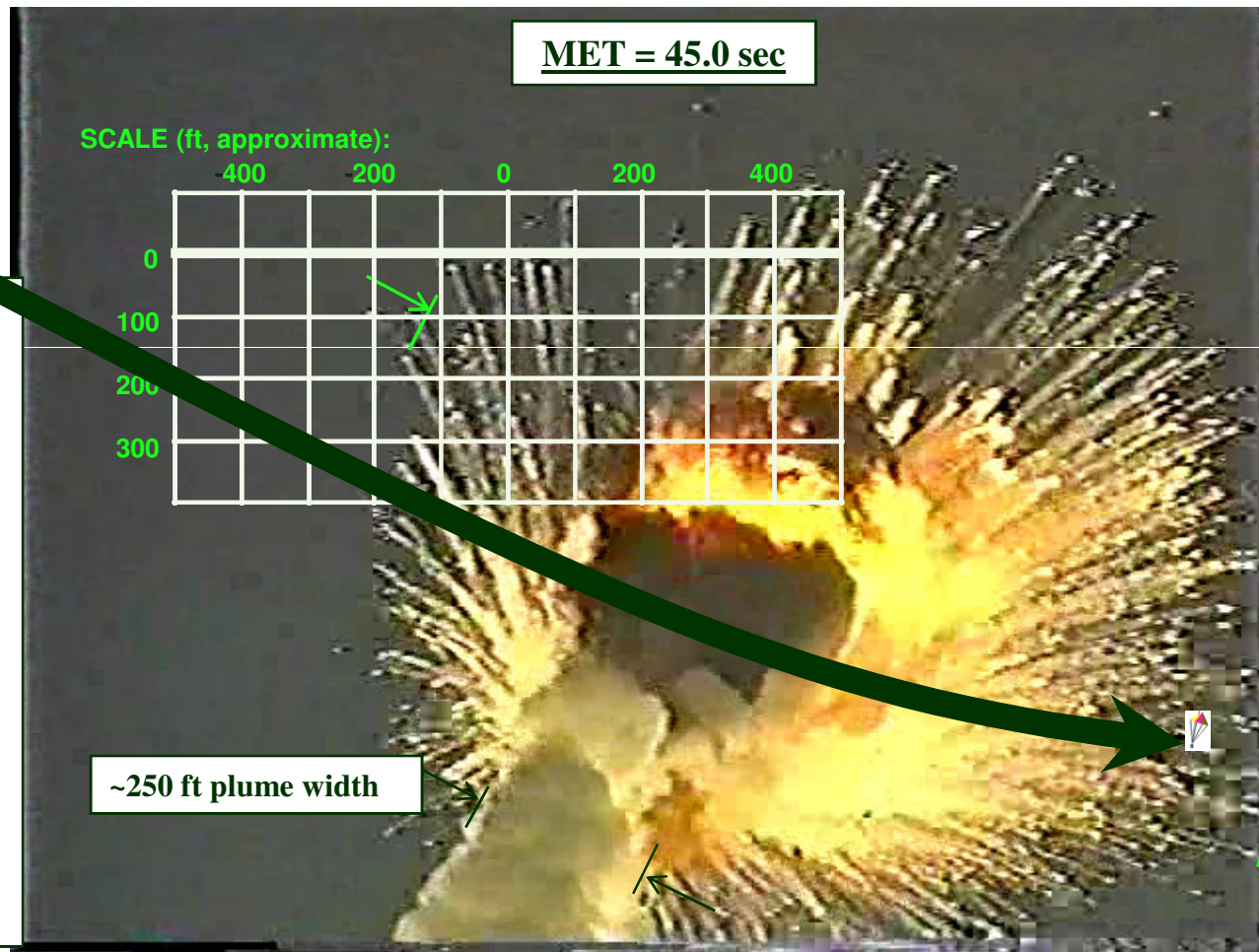
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CAPSULE

IS
~HERE

(i.e. no survival of parachutes – nylon w/ 400F melt temperature – at any time (from abort, through ground impact) following aborts at MET's between ~30-60 sec (when the Q windblast, rather than thrust, dominates the capsule trajectory)



~1500 ft-dia debris cloud (i.e. grew 150+ ft dia in 0.5 sec; $V_r = \sim 150$ +fps)

RESULTS: The TitanIV-A20 launch...

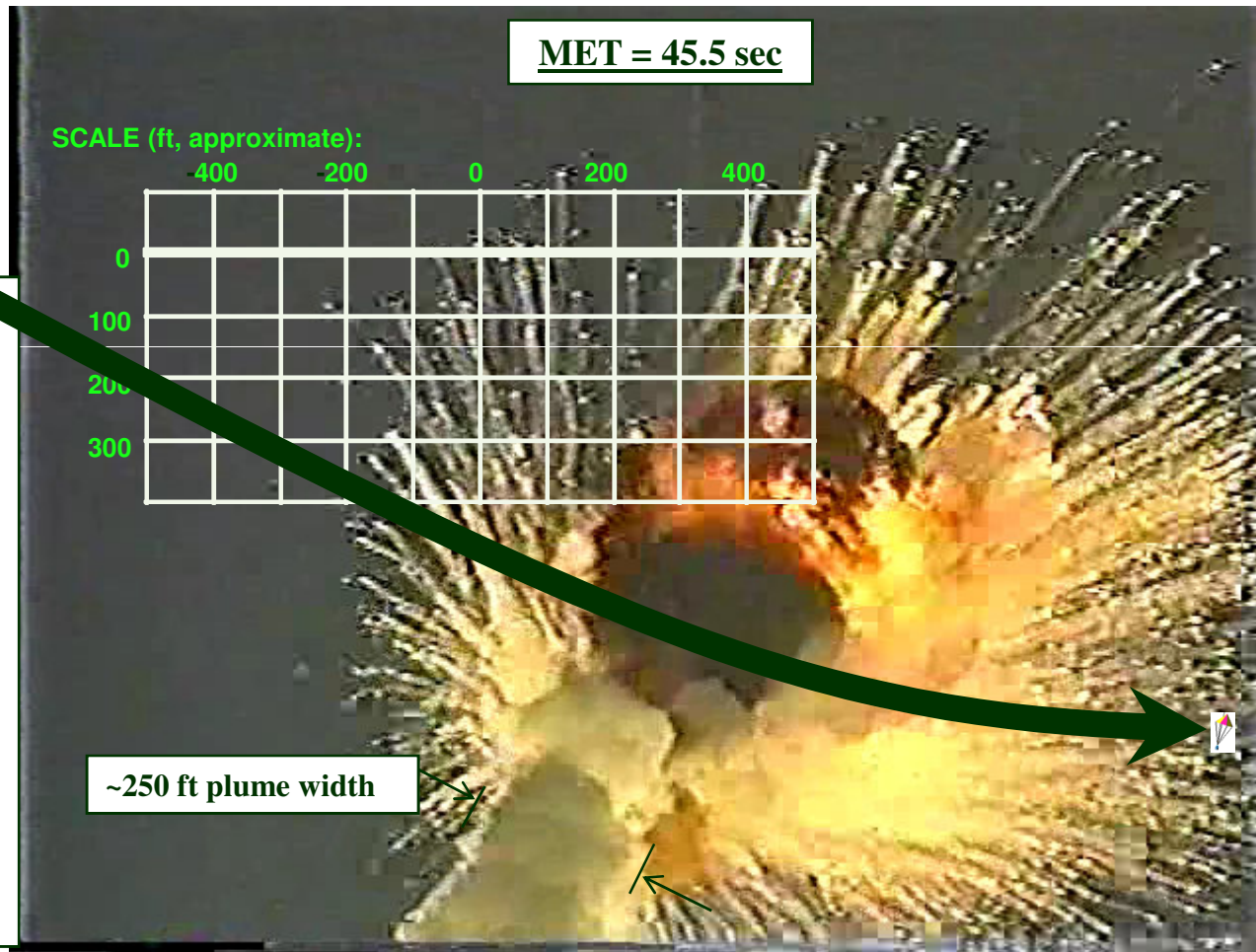
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~1700+ ft-dia debris cloud grows off the frame in ~ 3 seconds – w/ no fragments giving indication of slowing (i.e. no fragment has begun to visibly arc with gravity, yet)



RESULTS: The TitanIV-A20 launch...

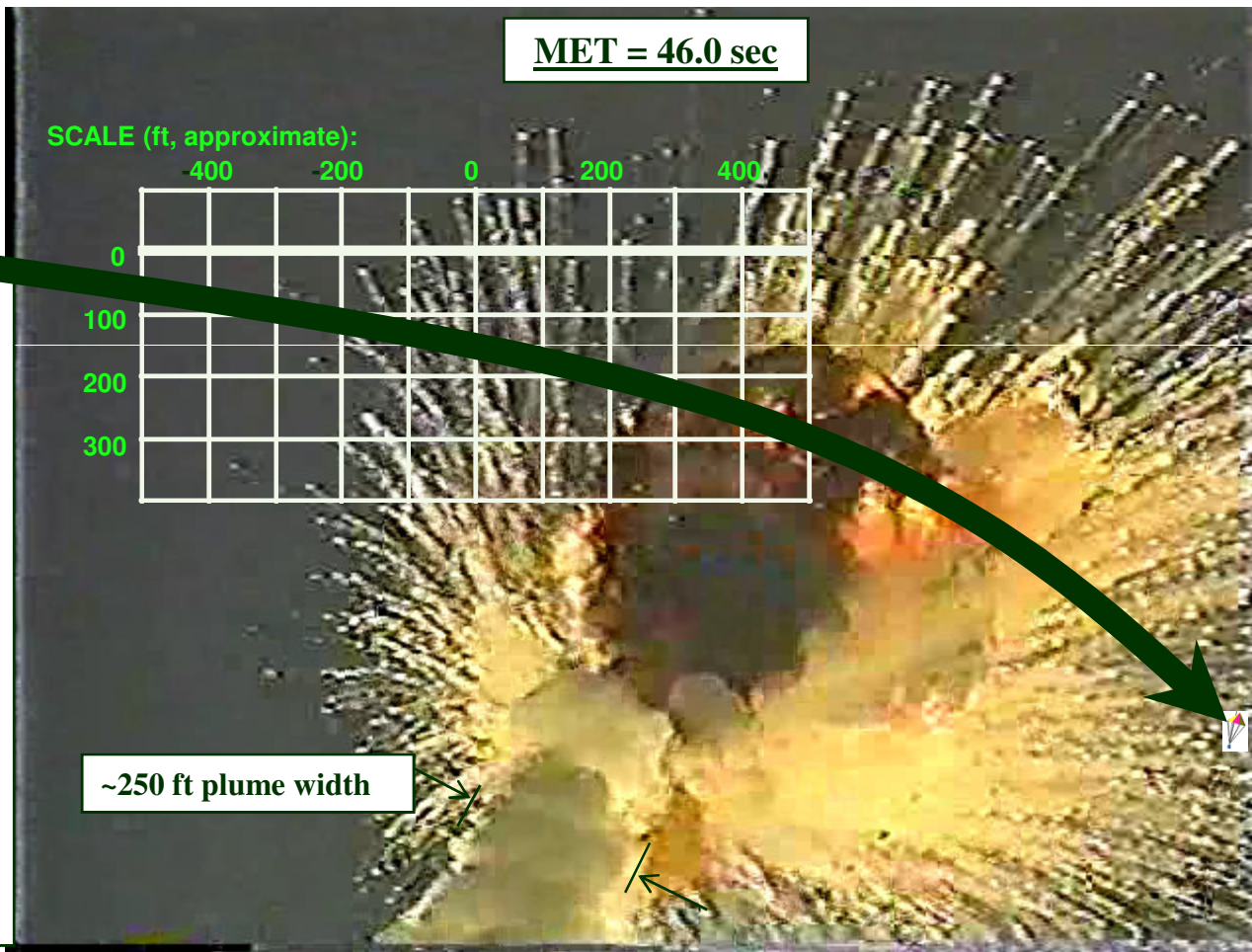
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~1900 ft-dia debris cloud grows off the frame, ~4 seconds from destruct, – w/ no sign of fragments slowing (i.e. no fragment has begun to visibly arc with gravity, yet)



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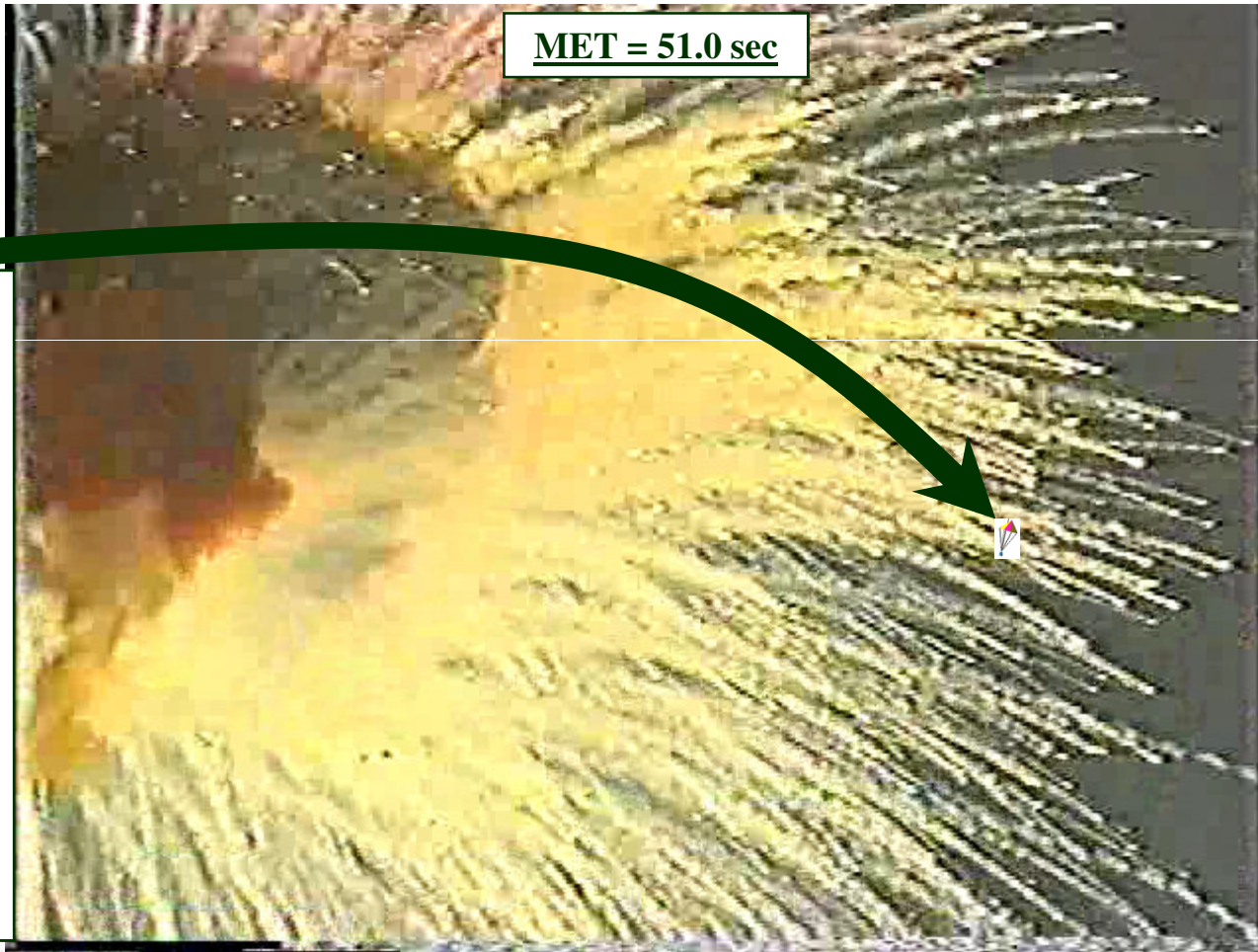
MET = 51.0 sec

CAPSULE

IS
~HERE

(i.e. no survival of parachutes – nylon w/ 400F melt temperature – at any time (from abort, through ground impact) following aborts at MET's between ~30-60 sec (when the Q windblast, rather than thrust, dominates the capsule trajectory)

Debris cloud continues growing at ~200 fps, ~9 seconds after destruct, – w/ moderate signs of fragments slowing (i.e. fragments have slightly arced with gravity)



RESULTS: The TitanIV-A20 launch...

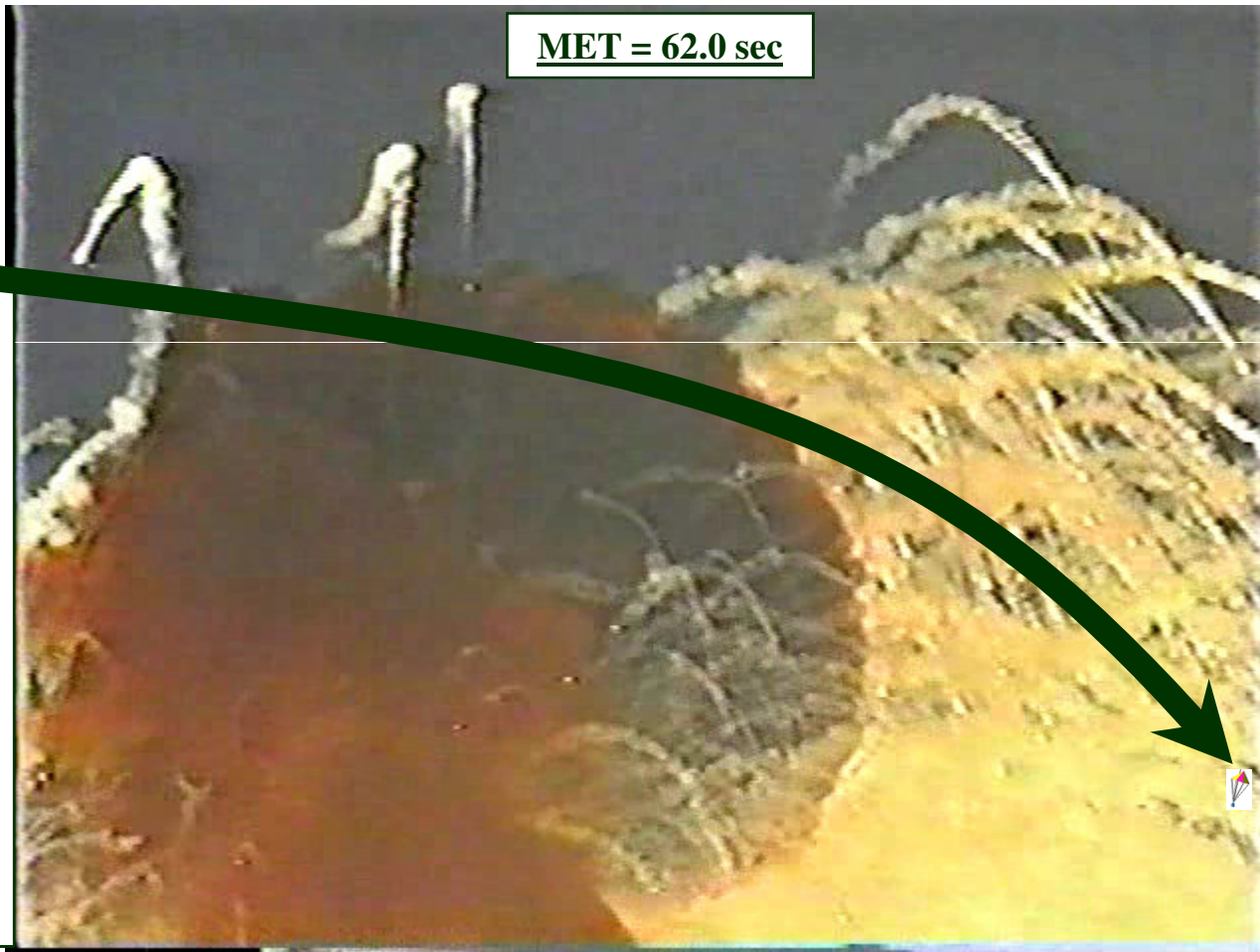
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~20 seconds after destruct, debris cloud has stopped expanding, and ~all fragments have begun to fall ~vertically toward a footprint that reportedly extended 3 miles across (~7,900 feet radius)

RESULTS: The TitanIV-A20 launch...

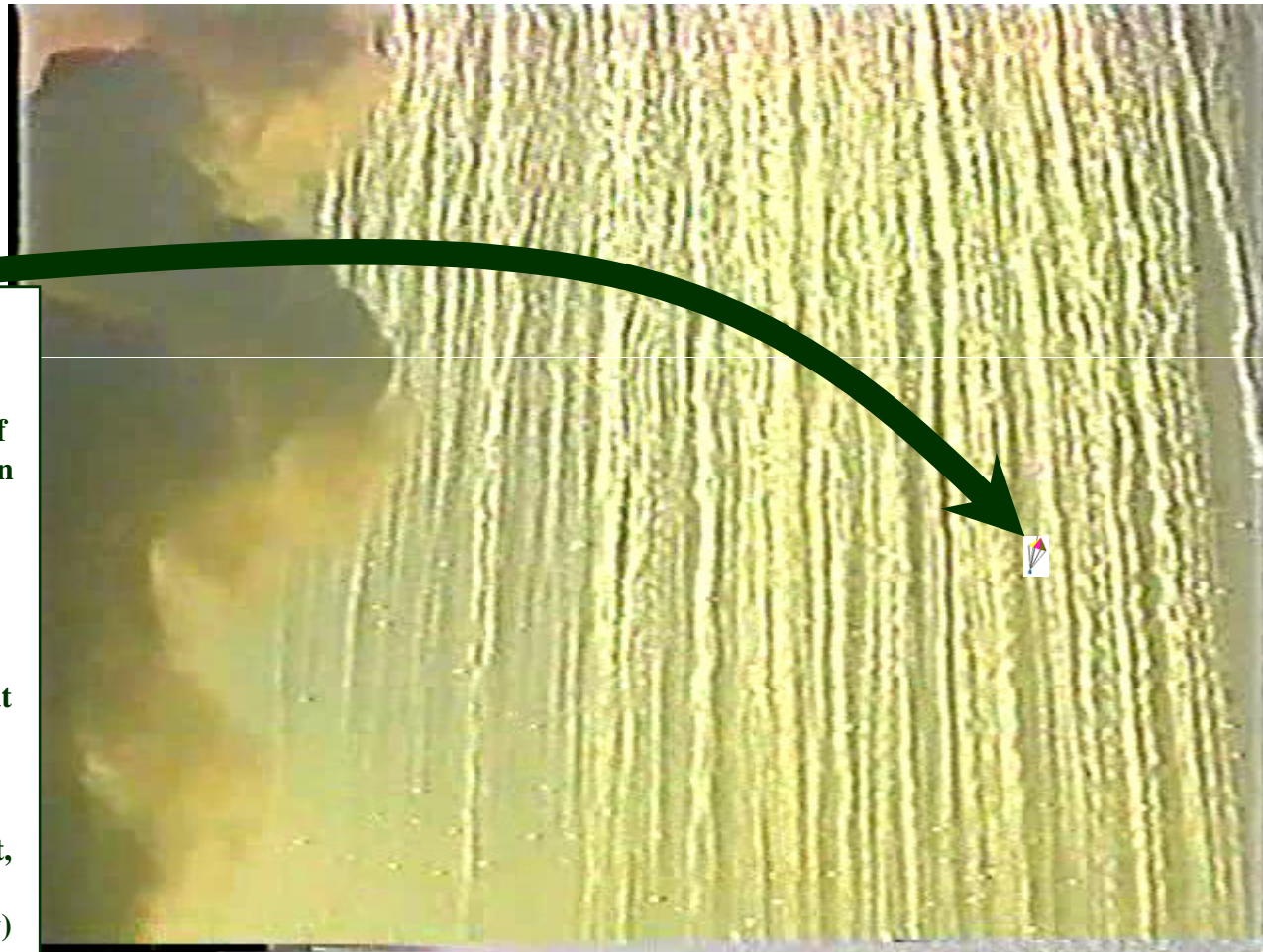
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4,000F

Environment:

For the several minutes of debris descent toward a ~3-mile diameter footprint on the ocean (~7,900 ft radius) – the hundreds of descending solid propellant fragments – many of which are several feet across and weighing hundreds or thousands of pounds - are flaming to create a network of 4,000F radiative heat, with ballistic coefficients greater and less than the capsule (i.e. capsule will be surrounded by these fragments, to ground)

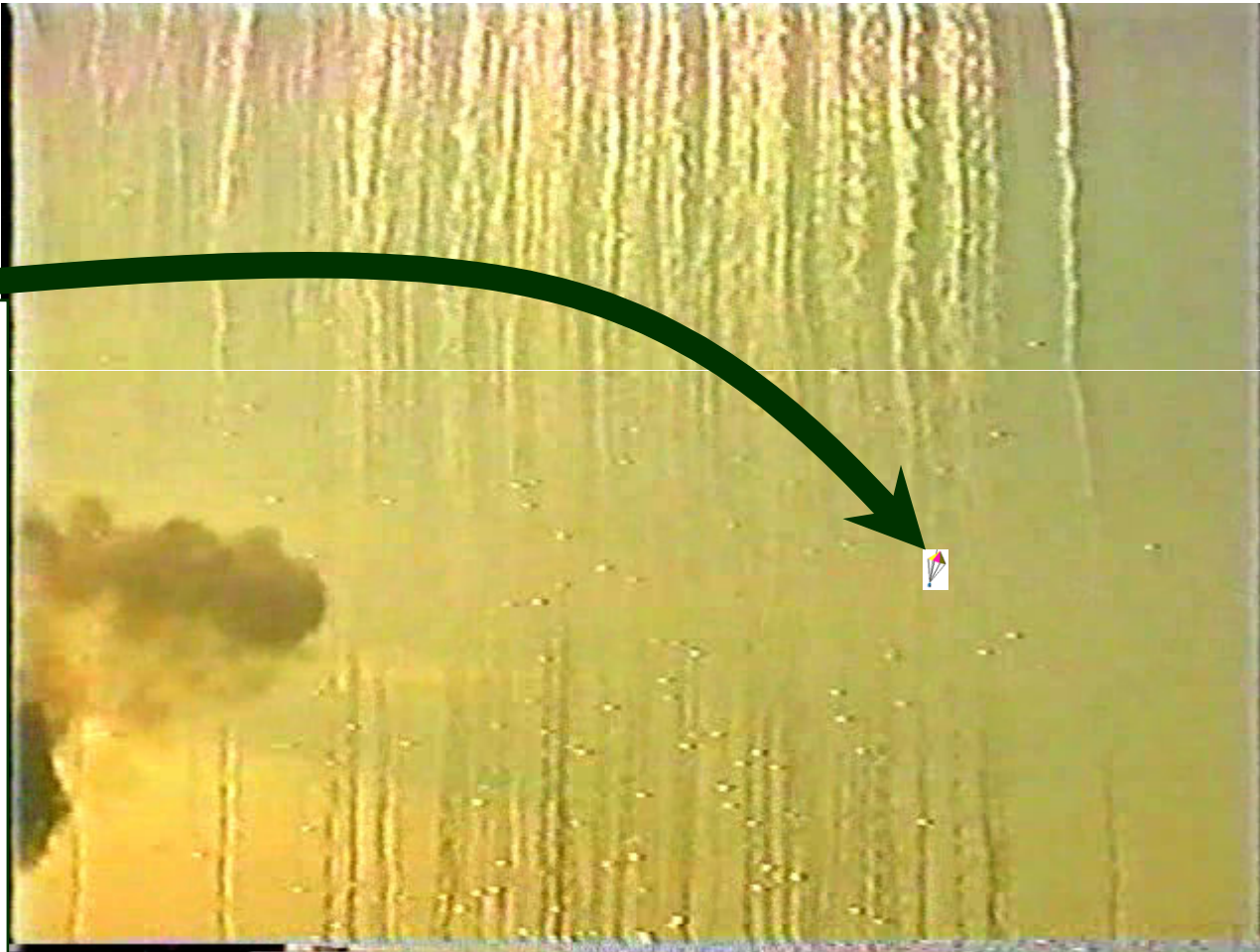
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CAPSULE IS ~HERE

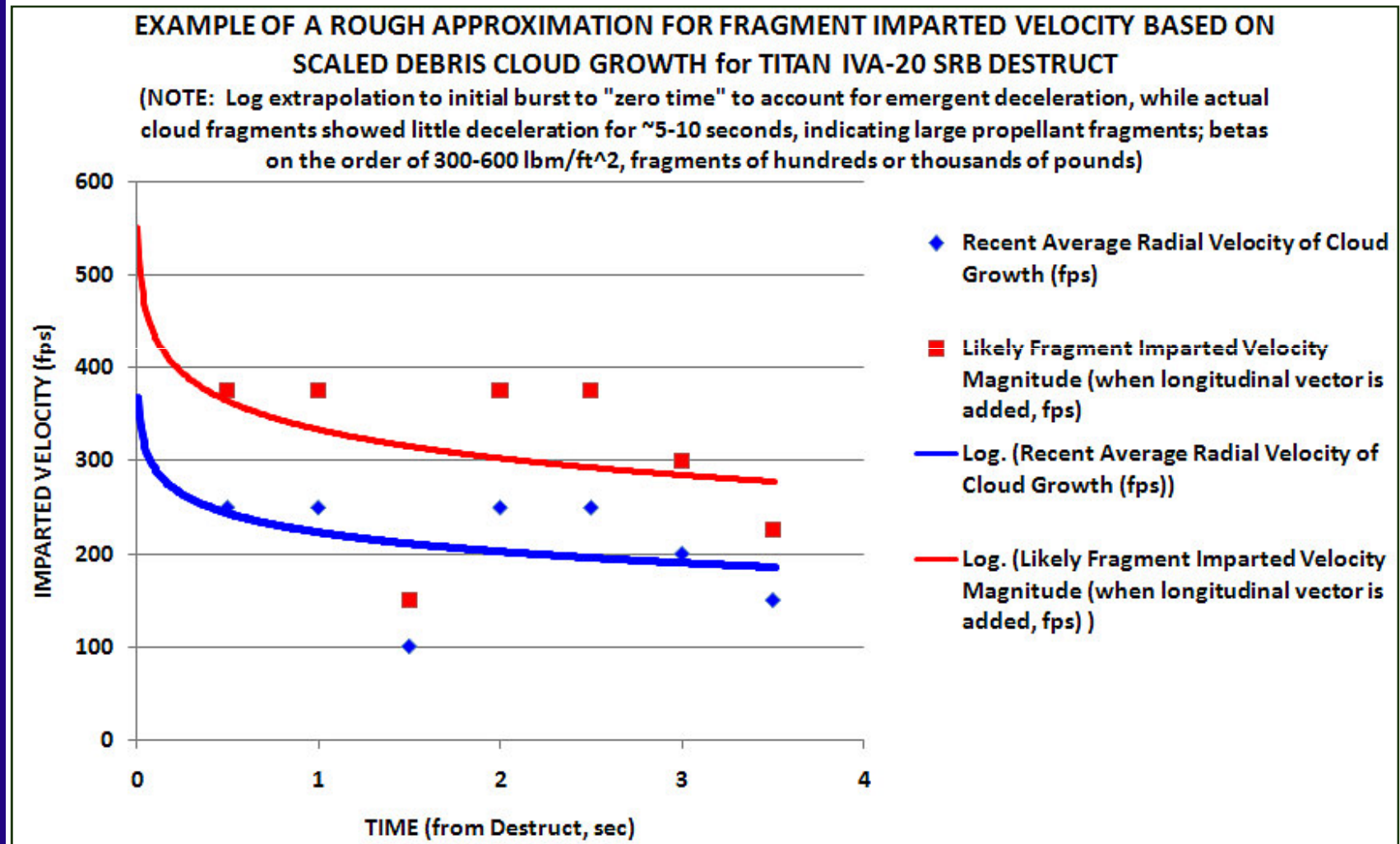
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RESULTS: Demonstrated Velocities...

Plotting the approximate radial velocity in cloud growth indicates imparted velocities of ~300-400 fps, possibly 300-600 fps; consistent with historical models, data studies, the NSWC-1981 Debris Catalog, and the June 2009 45th-SW-provided estimates.

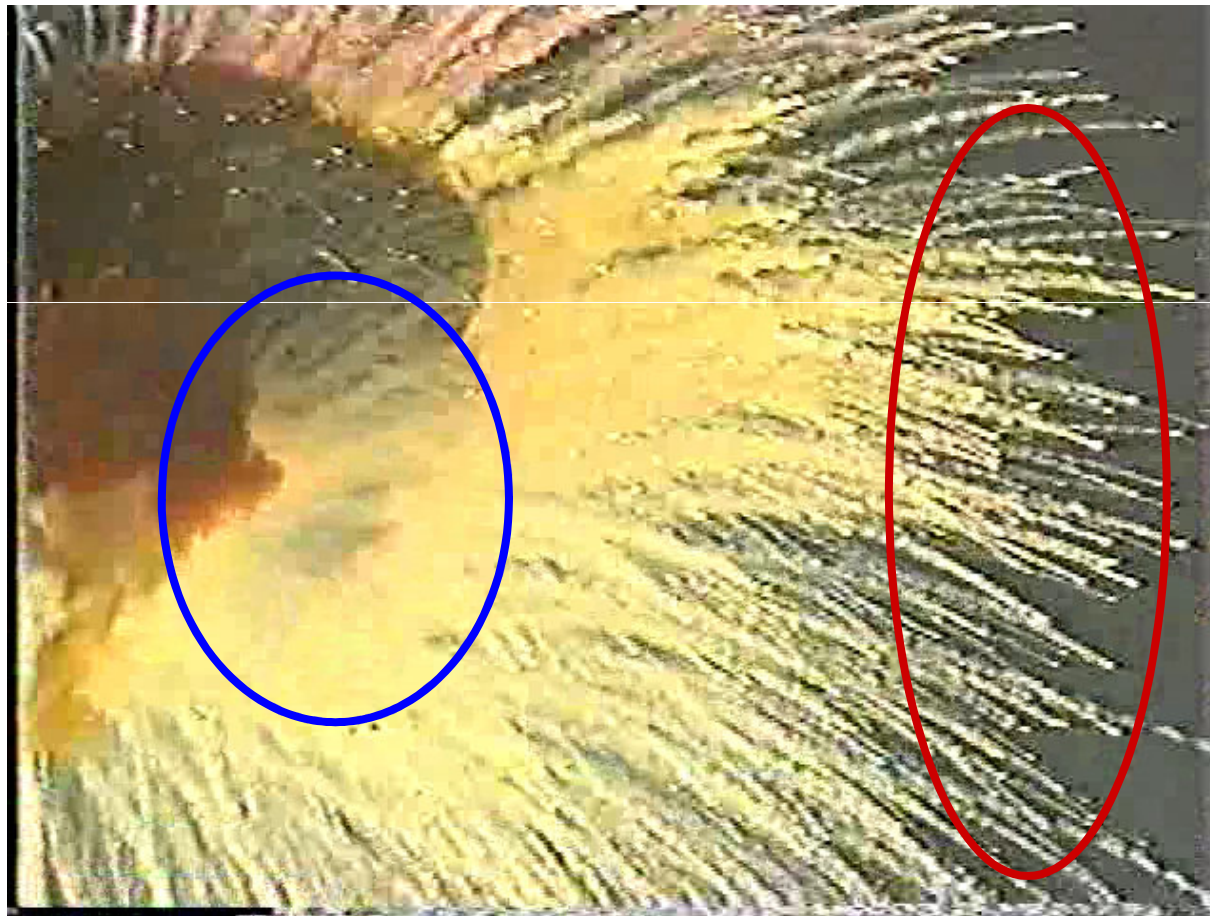


RESULTS: Small Velocity Variability...

While inference can't be certain, the "spherical dispersion" of the fragments appears to account for most of the "staggered" positions of the fragments (i.e. the only reason some fragments appear "closer to the burst" than others, is because they are AIMED toward or away from the camera). If so - the fragments are expanding out like a hollow sphere; a "shell" of fragments. In that case, the ground mixing of fragments is due to the relative beta drags and departure angles – while most fragments are initially at comparable radii from the burst, and therefore left the burst at approximately the same velocity magnitude (~300-600 fps). In that case: the variability of the burst velocity is small (i.e. +/-~10% - a variability of ~30 fps on the imparted velocity of 300-600 fps).



A hollow
"core" of
an
expanding
debris
cloud; few
fragments
traveling
slower



A dense
"shell" of
fragments,
expanding
as a hollow
sphere

FURTHER REFERENCES:



- **The 45th-Space Wing's**
“Constellation_45thConcernsOnNASADebrisCatalog”, Powerpoint presentation, 30 Oct 08
- **The 45th-Space Wing's**
“Constellation_45thConcernsOnNASADebrisCatalog_Summary”, Powerpoint presentation, 6 Mar 09
- **The 45th-Space Wing's presentation “45th_FragVelocityConcerns” of 17 April 2009**
- **The 6-DOF Trajectory Animation illustrating the debris and Ares-1 relationships: “45th_DebrisAnalysisMethodology_Ares1.wmv”**
- **The joint NASA/DOE/INSRP Explosion Working Group Final Report of the Titan-34D and STS-51L, 1989**
- **NSWC Debris Catalog of 1981**



CONCLUSIONS:

- The 45th-Space Wing has reasonable assessments for solid propellant debris fragment masses, velocities, etc.
- The Ares-1 capsule, with an LAS, will not survive an abort between MET's of ~30-60 seconds.

(High-Q is a risk from ~20-75 sec)

