General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

SIFT Teacher Action Plan

Daniel L. Evans
United Space Alliance, LLC (USA) at KSC
Summer 2007

The Physics of the Columbia Accident Investigation

Overview

The Columbia Accident:
Loss of Orbiter and Crew upon Reentry on February 1, 2003

Part 1: The Cause

- Estimating Foam Debris size Using Ratios
- Calculating Mass and Speed for Kinetic Energy behind the collision

Part 2: The Search for the Flight Data Recorder

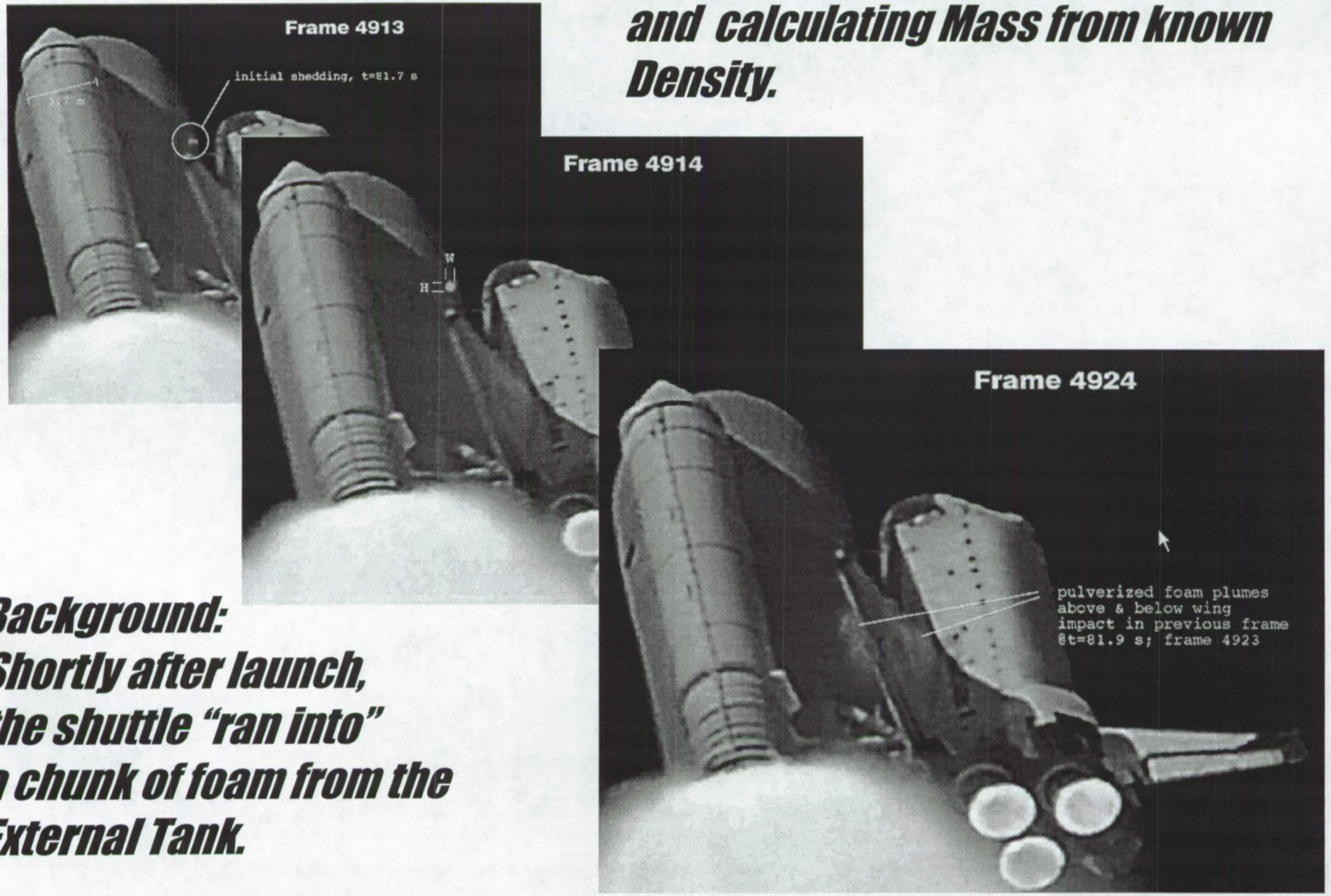
Calculating a Parabolic Trajectory with a Drag Coefficient

"How did this happen?"

"How can we stop it from happening again?"

PART 1

Determining Foam Size by SCALING, and calculating Mass from known Density.



Background:
Shortly after launch, the shuttle "ran into" a chunk of foam from the External Tank.

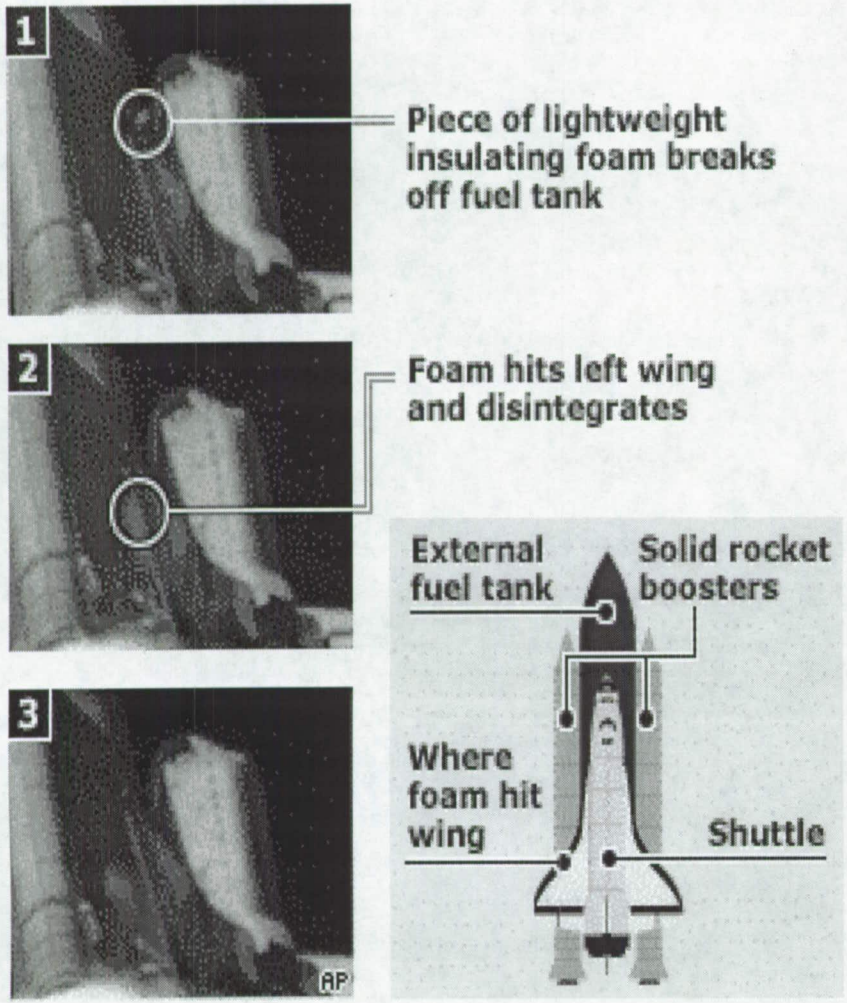
When the Columbia and External Tank were both traveling at 1568 mph, a piece of foam separated from the External Tank.

0.161 seconds later, the foam had slowed to 1022 mph, while the Columbia and External Tank continued along at about 1568 mph.

The difference in speeds is 545 mph.

Essentially, the shuttle "ran into" the foam at 545 mph.

"Should we be worried about damage to the Columbia?"

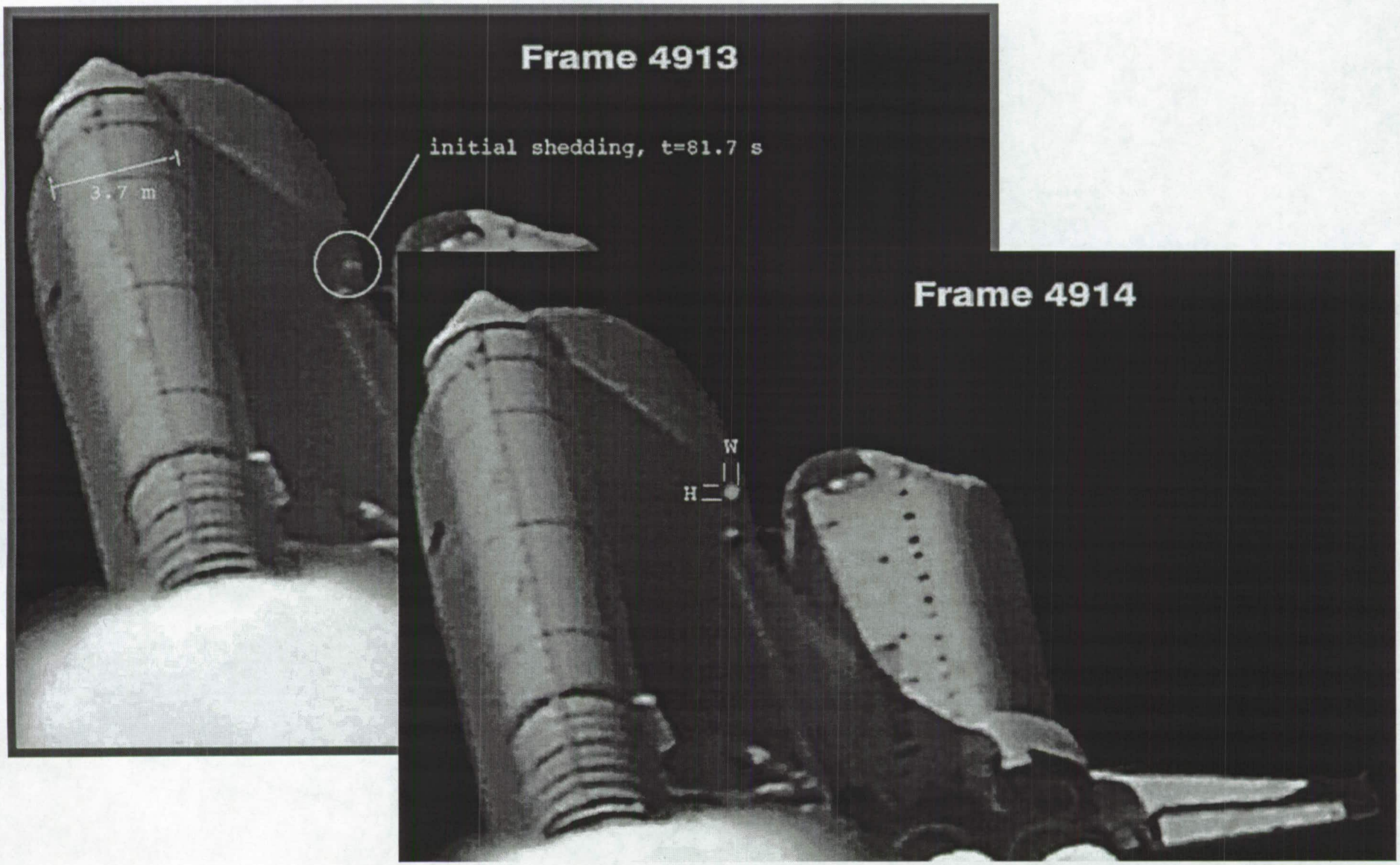


How big was the piece of foam?

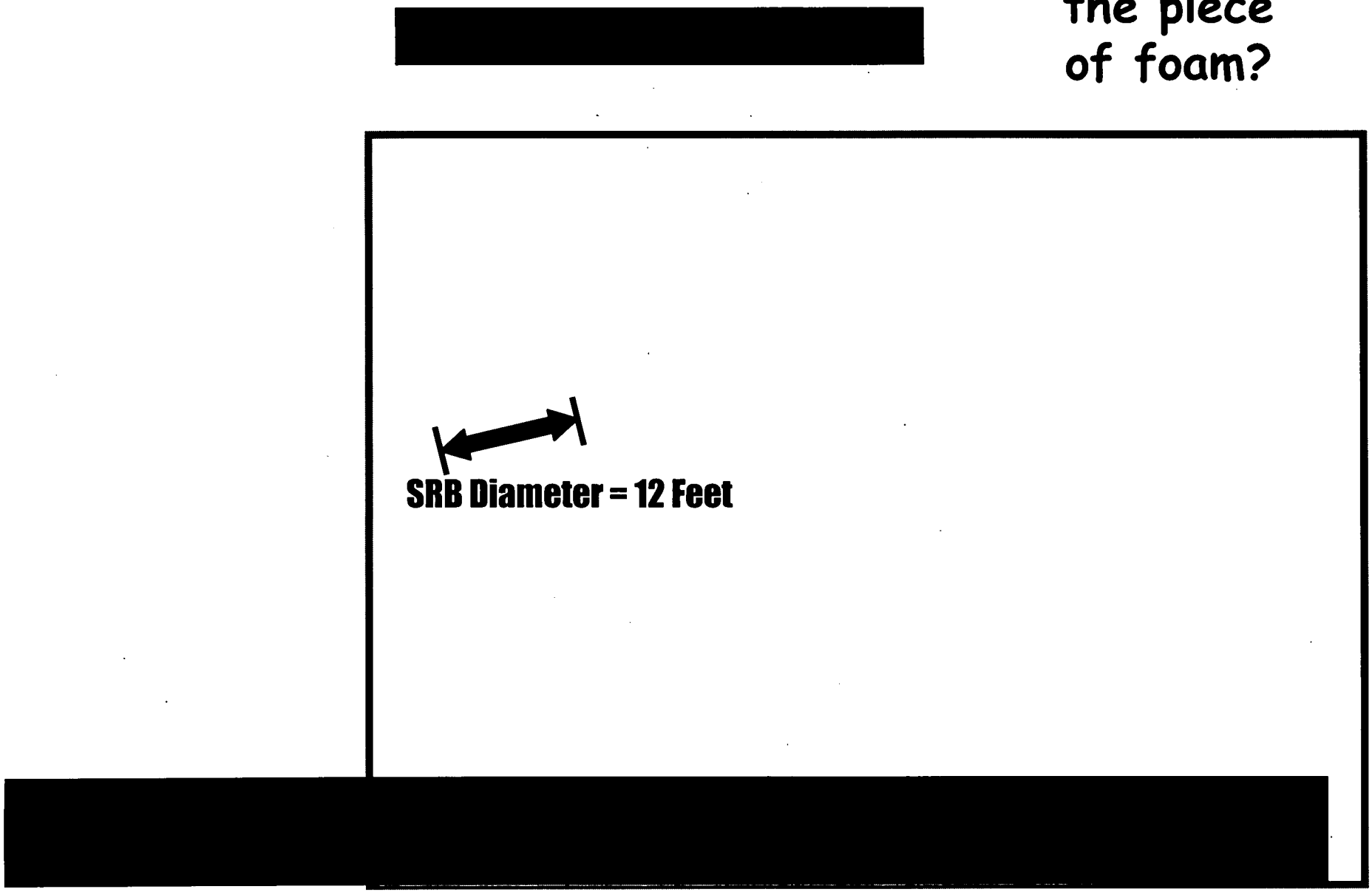
How dense was it?

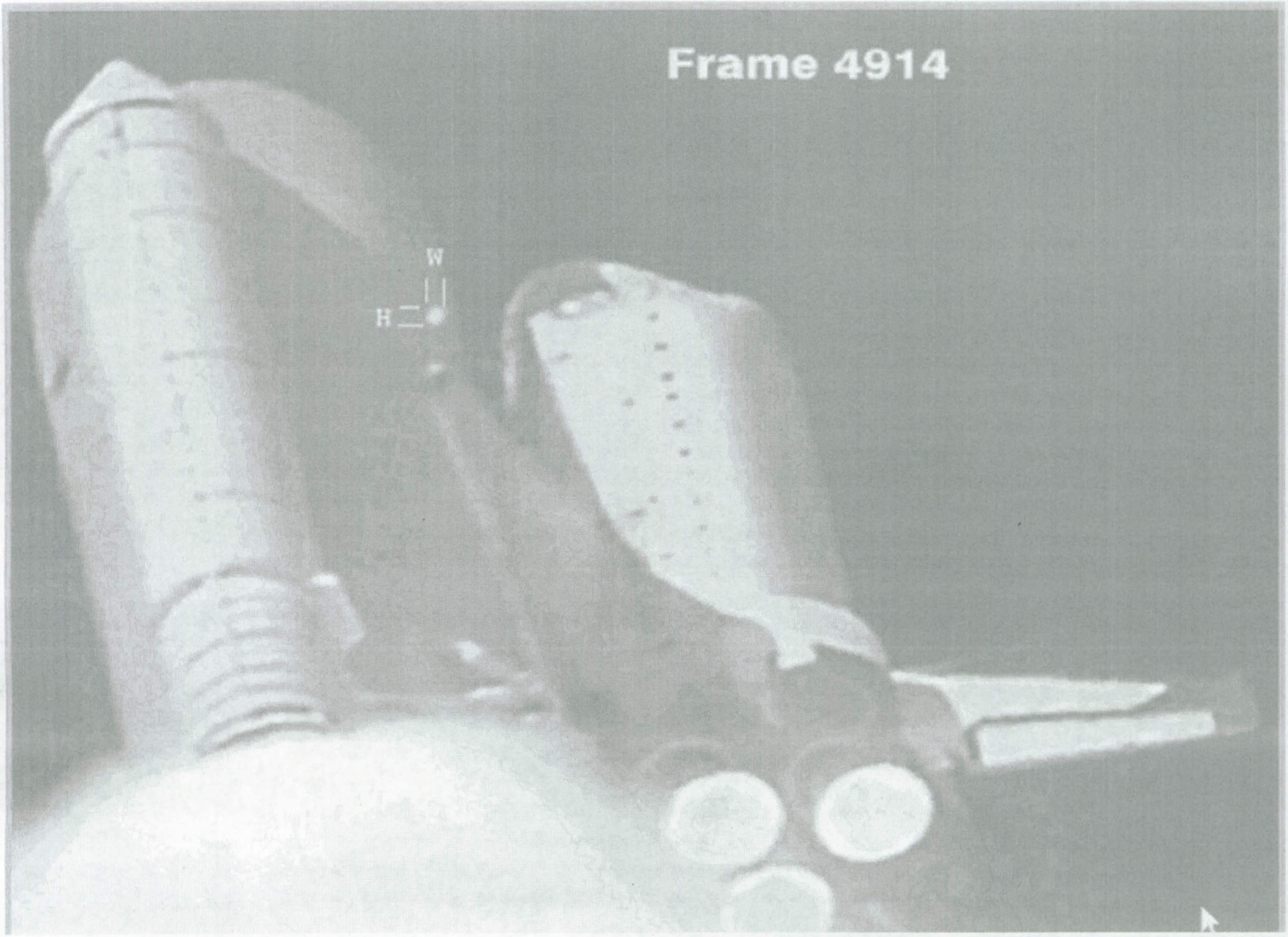
How fast was it going?

What would you have thought at the time?

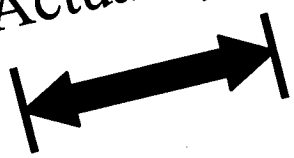

Frame 4913
initial shedding, t=81.7 s
3.7 m
Frame 4914
W
H

How big was the piece of foam?




Frame 4914
W
H

12 ft = **144 inches**
(Actual Diameter)

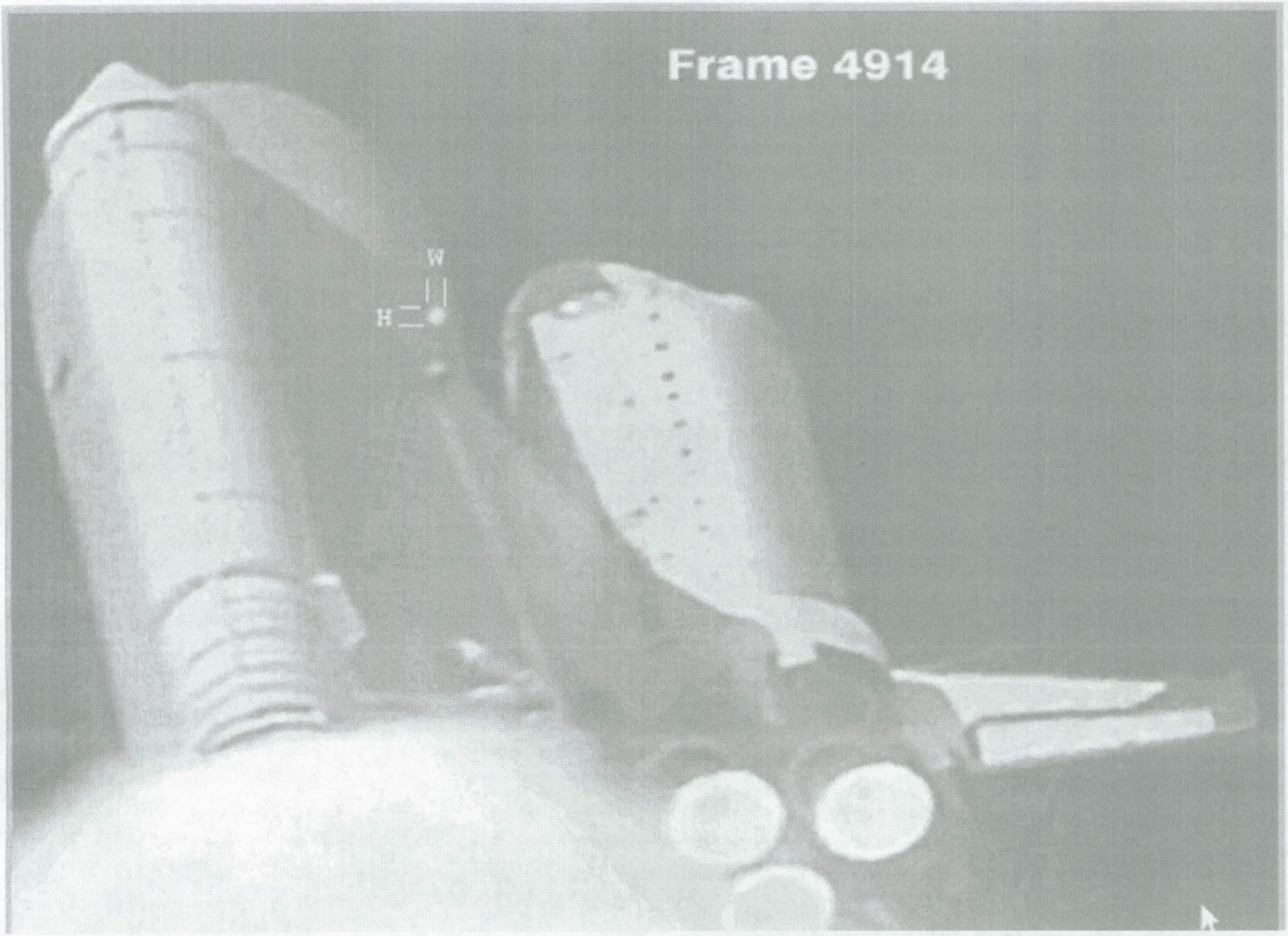


Foam's Actual Width W is unknown.
Foam's Actual Height H is unknown.

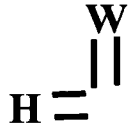
Apparent diameter
(on photograph)
= **0.9 inches.**

Foam's Apparent height h is 0.119 inches.
Foam's Apparent width w is 0.072 inches.

We can use the known relationship (proportion) between the Actual Diameter of the SRB and the apparent diameter as seen in the image to find the Actual Width and Height of the Foam seen in this image.


Frame 4914
W
H

12 ft = **144 inches**
(Actual Diameter)



Foam's Actual Width W is unknown.
Foam's Actual Height H is unknown.

Apparent diameter
(on photograph)
= **0.9 inches.**

Foam's Apparent height h is 0.119 inches.
Foam's Apparent width w is 0.072 inches.

$$\frac{144}{0.9} = \frac{H}{0.119}$$

(cross multiply)

$144 \times 0.119 = 0.9H$

H = 19 inches

$$\frac{144}{0.9} = \frac{W}{0.072}$$

(cross multiply)

$144 \times 0.072 = 0.9W$

W = 11.5 inches

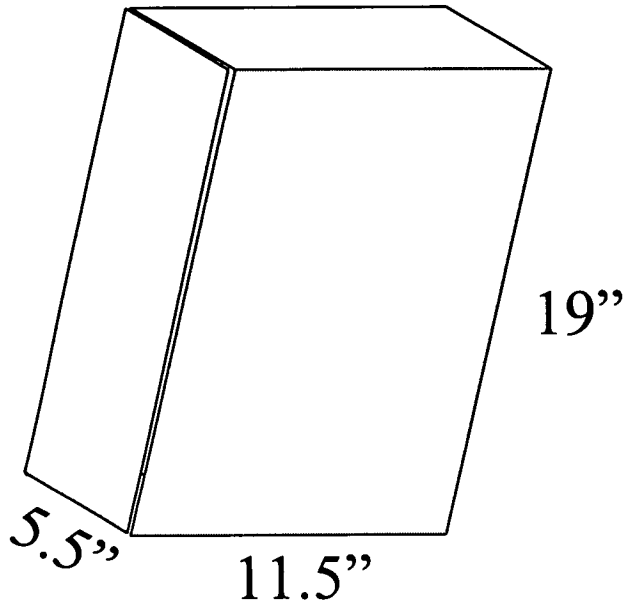
What about the thickness of the Foam?

It's known to be applied 5.5 inches thick.

...so its volume is...

Length times width times height.
Density is given in lbs/cubic ft,
so let's convert from inches to feet:

$$\frac{5.5}{12} \times \frac{11.5}{12} \times \frac{19}{12} = 0.696 \text{ ft}^3$$



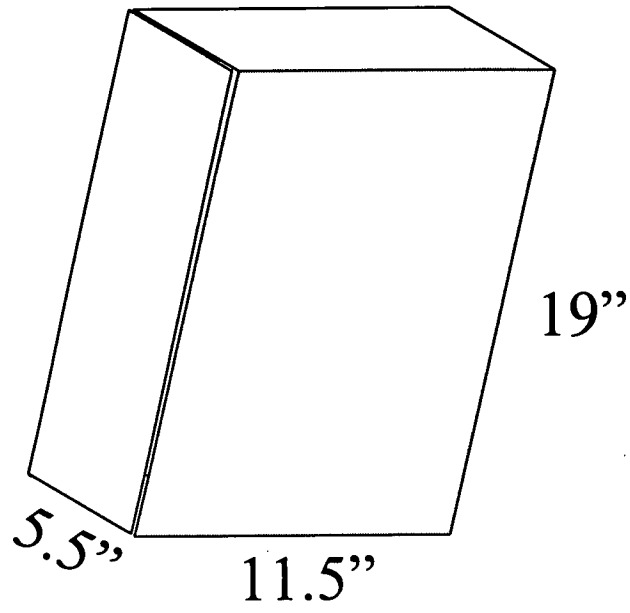
...and we know the Foam's density is 2.4 lb/ft^3, so its mass is:

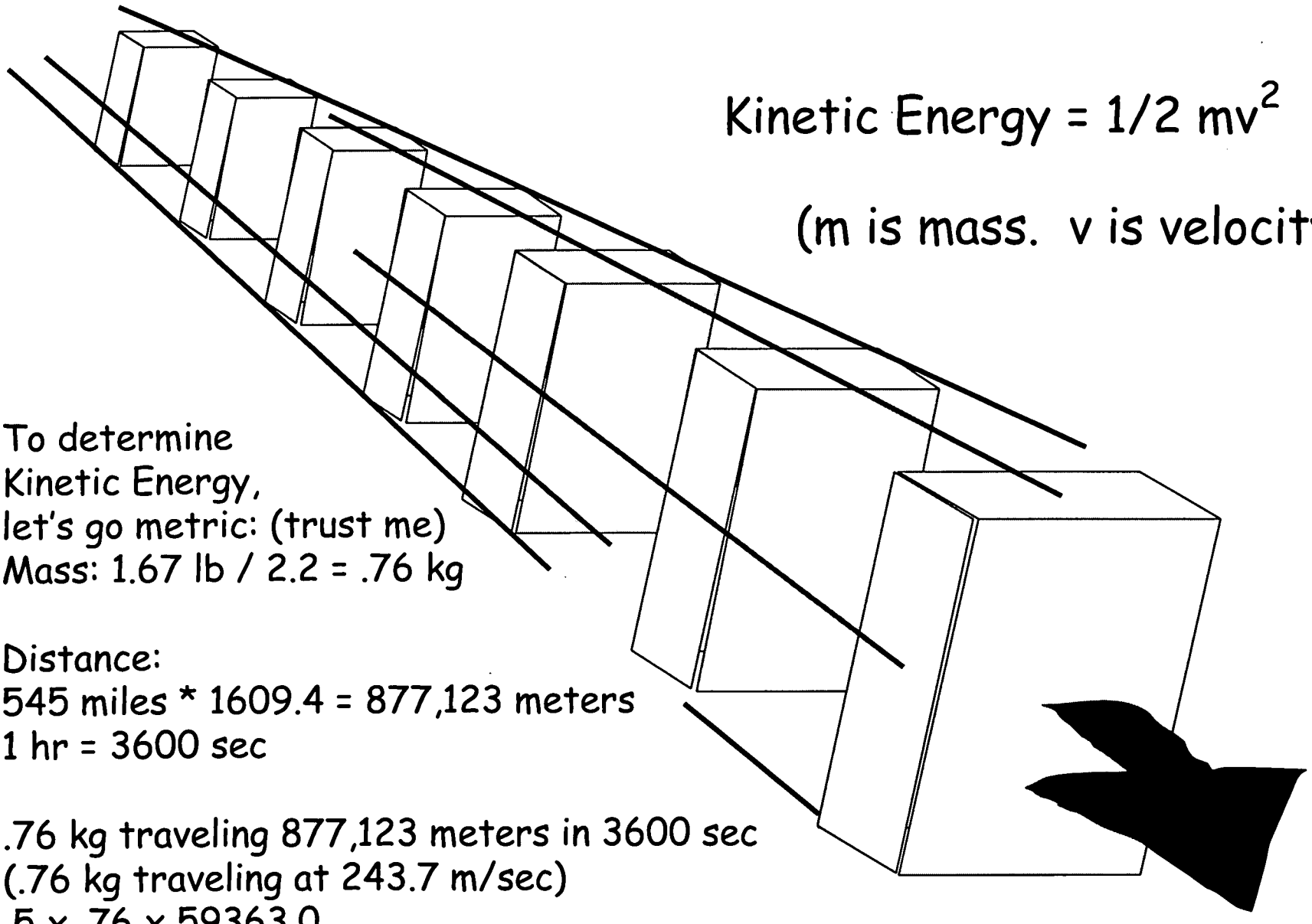
$$.696\ ft^3 \times 2.4\ \frac{lb}{ft^3} = 1.67\ lb$$

Is that a lot?

hmm, we'll need to know the Foam's speed!

Looking at how far it traveled in one frame of film, its speed can be determined to be About 545 miles per hour.





Kinetic Energy = $1/2\ mv^2$

(m is mass. v is velocity.)

To determine
Kinetic Energy,
let's go metric: (trust me)
Mass: 1.67 lb / 2.2 = .76 kg

Distance:
545 miles * 1609.4 = 877,123 meters
1 hr = 3600 sec

.76 kg traveling 877,123 meters in 3600 sec
(.76 kg traveling at 243.7 m/sec)
.5 x .76 x 59363.0
=22,558.0 Joules. One joule is the energy you feel if an apple is dropped on you from a meter above.

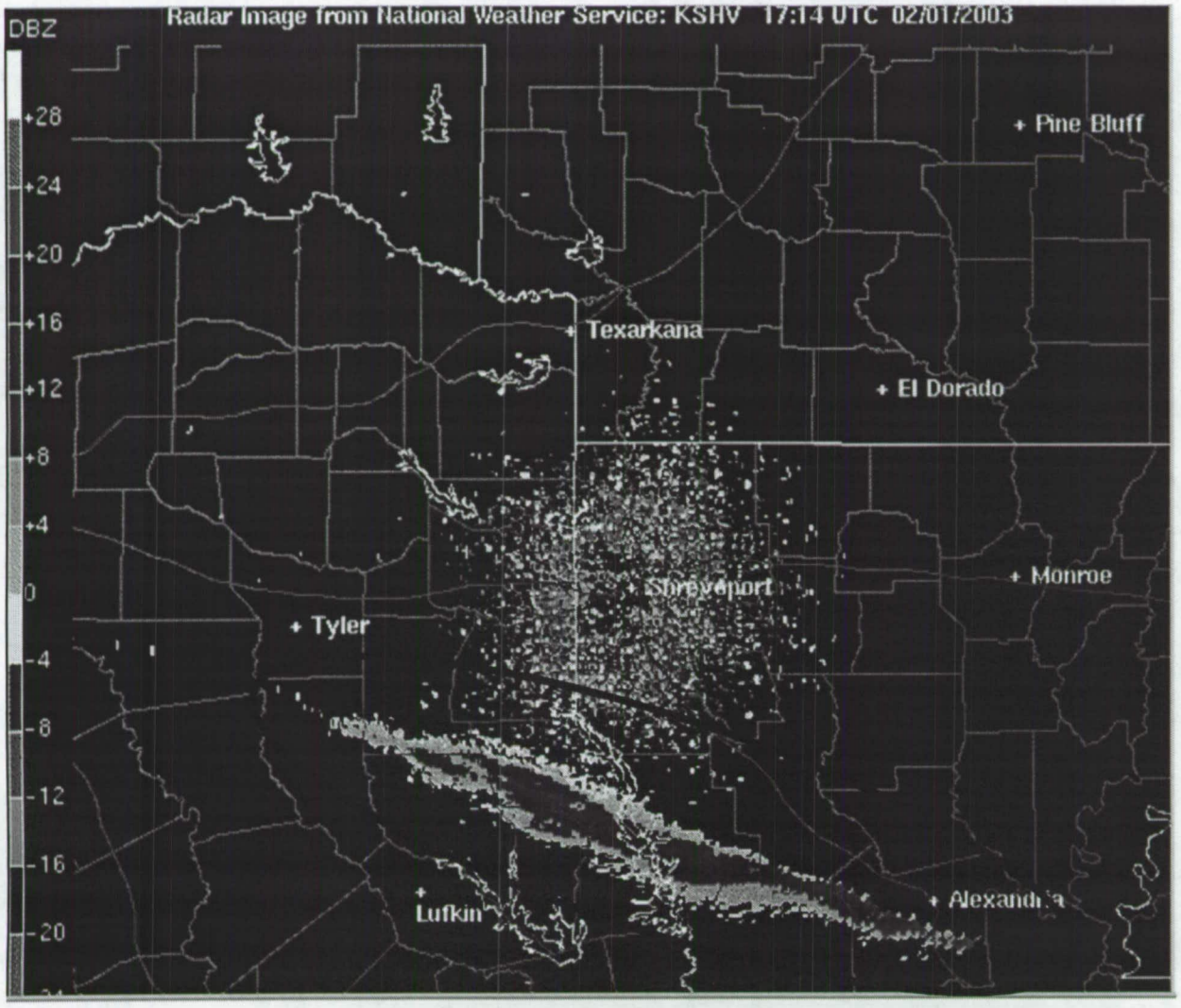
22,558 joules

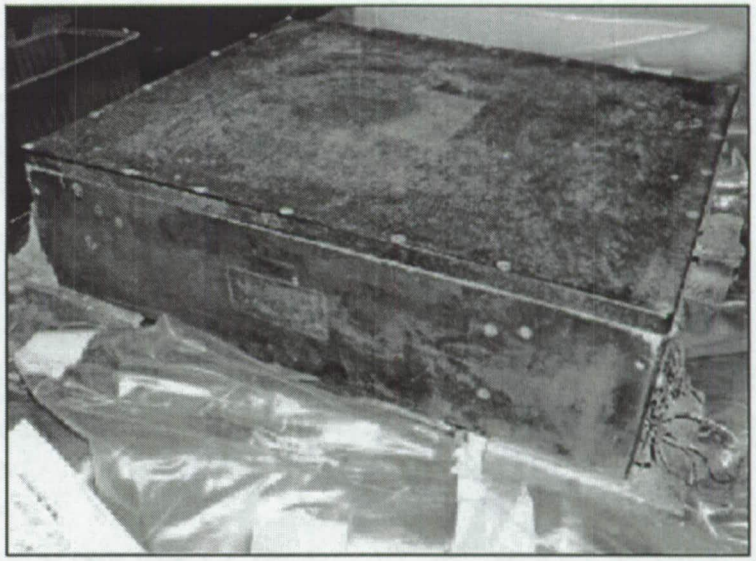
For comparison, a 9mm gun fires a bullet with a muzzle energy of about 500 joules.

Some of that energy went into the foam as it disintegrated at impact.
Some of that energy went into Columbia's left wing.

Many engineers were concerned about this impact before Columbia returned to earth, but organizational issues allowed them to be ignored.

PART 2 The search for the Flight Data Recorder: Where did it come down?

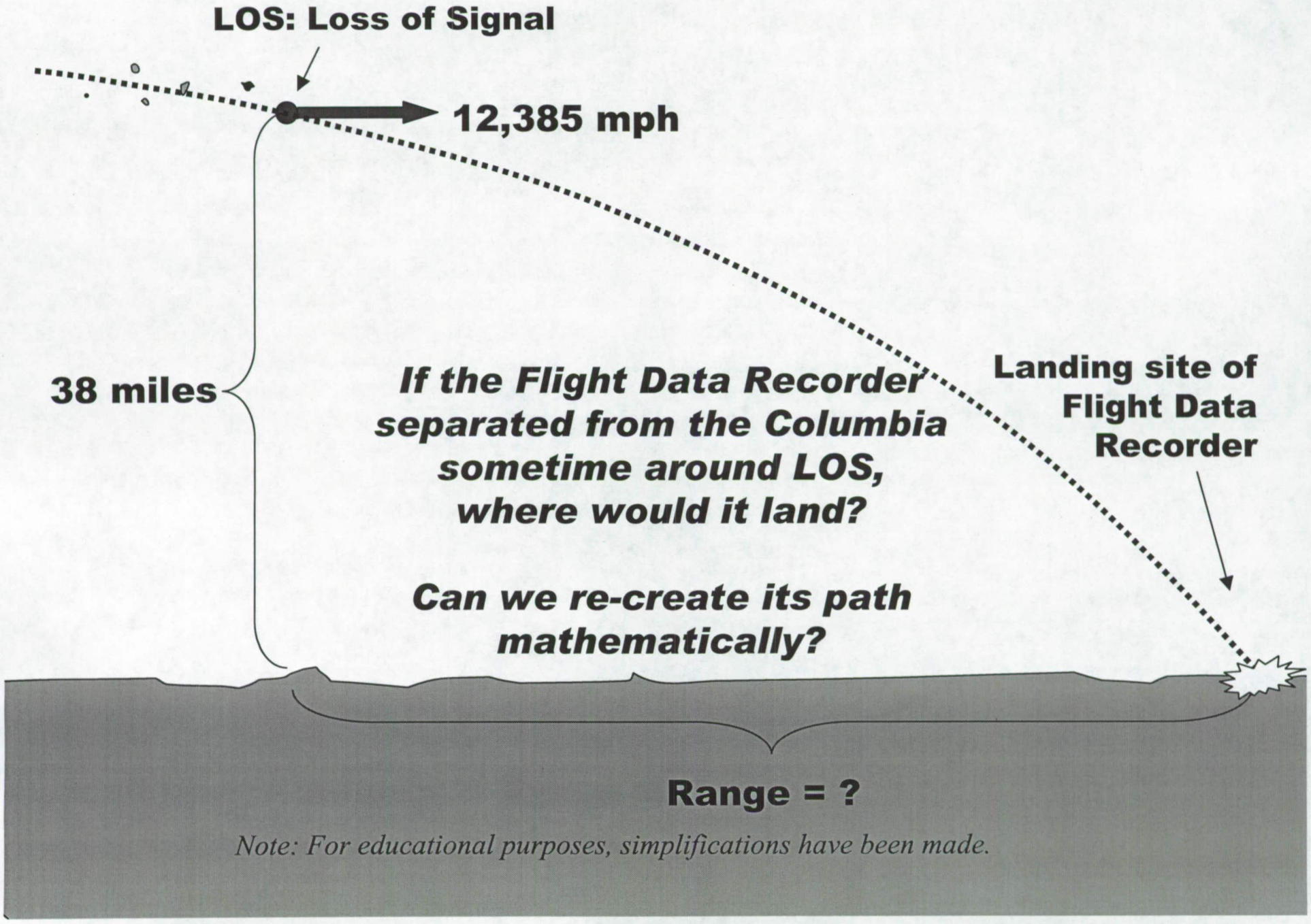




Texas

Louisiana

he Debri s Field stretched for hundreds of miles.


LOS: Loss of Signal
12,385 mph
38 miles
If the Flight Data Recorder separated from the Columbia sometime around LOS, where would it land?
Can we re-create its path mathematically?
Landing site of Flight Data Recorder
Range = ?
Note: For educational purposes, simplifications have been made.

$$R = v_o\sqrt{\frac{h}{4.9}} - C_D v_o$$

R = Range
v_o = initial horizontal velocity
h = height (altitude)
C_D = Drag Coefficient

Given: C = 2.75
v_o = 12,385 mph
h = 38 miles
…what is the Range?

answer:
Range = 310 miles

PART 3: Using Trigonometry to determine Altitude of a Rocket

Materials: (Instructions provided separately)

- Paper Rocket
- Rocket Launcher built from PVC pipe
- Inclinometer made from a Protractor

Note: Part 3 does not feature any information from United Space Alliance