This sequence of images was taken of the launch of the Juno spacecraft on August 5, 2011 from Cape Canaveral. The images were taken, from left to right, at T+21, T+23 and T+25 seconds after launch, which occurred at 12:25:00 pm EDT. The original video can be found on *YouTube*. The distance from the base of the Atlas-Centaur rocket to its top is 45 meters (148 feet). As the video was produced, the camera zoomed-out between the T+21 image and the T+23 image. Both the T+23 and T+25 images were taken at exactly the same zoom scale.

Problem 1 - From the information given, find the speed of the rocket in meters/sec and kilometers/hr between A) 21 and 23 seconds after launch and B) 23 to 25 seconds after launch.

Problem 2 - What is the average acceleration of the rocket in meters/sec^2 between 21 and 25 seconds after launch?

Problem 3 - At the average acceleration of this rocket, about when will it be traveling faster then the speed of sound (Mach 1) which is 340 meters/sec?

Problem 1 - From the information given, find the speed of the rocket in meters/sec and kilometers/hr between A) 21 and 23 seconds after launch and B) 23 to 25 seconds after launch.
Answer: Students will need to determine the scale of each image by using a millimeter ruler to measure the length of the rocket body, which is known to be 45 meters. When printed using a regular laser printer, the lengths of the rockets are about 21) 5.5mm 23) 4.0 mm and 25) 3.0 mm
The image scales are therefore 8.2 meters/mm, 11.3 meters/mm and 15 meters/mm

To measure speed, all we need to do is measure the height of the bottom of the rocket vertically from a well-defined point near the bottom of the image away from the exhaust cloud. The horizontal band of water just below the exhaust plume provides a good reference. Using the millimeter ruler we get 21) 35 mm 23) 36 mm and 25) 43 mm Converting this in to meters using the three scales we get 21) 287 meters 23) 407 meters and 25) 645 meters

Speed: 21 to 23 seconds; s1 = (407-287) / 2 sec so s1 = **60 meters/sec**
23 to 25 seconds: s2 = (645 - 407)/ 2 sec so s2 = **119 meters/sec**

In km/h we get s1 = **216 km/hour** and s2 = **428 km/hr**.

Students estimates will vary depending on the method and measuring accuracy used.

Problem 2 - What is the average acceleration of the rocket in meters/sec^2 between 21 and 25 seconds after launch?

Answer: acceleration = difference in speed/difference in time so
Acc = (119 meters/sec - 60 meters/sec) / (4 seconds)
= **15 meters/sec^2**

Problem 3 - At the average acceleration of this rocket, about when will it be traveling faster then the speed of sound (Mach 1) which is 340 meters/sec?

Answer: speed = initial speed + acceleration x time

340 = 119 + 15 x T

So **T = 15 seconds after the initial speed** of 119 m/s was reached. This occurs about T = 25 sec + 15 sec = **40 seconds after launch**.

According to actual flight information, Mach 1 was reached a bit later at T+ 51 sec.