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There is a great deal to be learned from an analysis and discussion of the topic of reentering space objects and their legal implications. A great many questions can be asked and perhaps the experts contributing to this Symposium will be able, for the first time to my knowledge, to offer some considered and creditable answers. There has been a great deal of speculation, interpretation and misinformation in the press in recent months on this subject. Hopefully, this Symposium will help to clear our vision and clarify our thinking on this fascinating and important subject. This presentation will begin with some technical, factual information and a brief explanation of the mechanics of reentry.

When trying to describe an unfamiliar subject it is always useful to try to begin with a reference to something familiar. A few statistics which will follow, if not widely known, are very pertinent to our topic.¹ They represent facts with which familiarity is a prerequisite for an understanding of the subject matter.

The total number of man made objects which have been placed in orbit about the earth up to March 31, 1978 is 10,791. This number includes satellites, rockets, pieces of shrouds and other nonfunctional debris. If an object is in earth orbit, it will eventually come down. The higher the orbit and the greater the speed of an object the longer it will remain aloft, but eventually it will come down. For the 10,791 objects that have been placed in space, a box score as of March 31, 1978 is indicated in the Table infra:

The following statistical data are known because the United States Air Force North American Air Defense command (NORAD) conducts space tracking operations which permit discovering and monitoring the status of all objects launched into space, whether by the United States or by another country. Among other functions, the NORAD Space Defense Center also compiles predictions for satellites, rockets and other pieces of debris that are likely to survive burnup in the friction of atmospheric reentry.² These predictions are updated periodically and provided to interested government agencies.

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¹The statistical data, including the tables (figures), herein contained are taken from The Satellite Situation Report for March, 1978 issued by NASA's Goddard Space Flight Center, Greenbelt, MD.

²It does not formulate such predictions on smaller fragments that are assured of burning up on reentry.

<u>COUNTRY</u>	<u>OBJECTS IN ORBIT</u>	<u>DECAYED OBJECTS</u>
Australia	1	1
Canada	8	0
ESA	5	9
France	53	27
France/Germany	2	0
Germany	9	3
India	1	0
Indonesia	2	0
Intelsat	23	0
Italy	1	4
Japan	31	0
NATO	4	0
Netherlands	0	4
PRC	5	17
Spain	1	0
United Kingdom	11	4
US	2997	1549
USSR	1447	4572

Before returning to the topic of predicting—particularly predicting reentry time and place—it may be convenient to look briefly at some famous, well-known and, hopefully, familiar space objects that have reentered and will be reentering our atmosphere. The relevant tables (figures) follow at the end of this presentation.

In Figure 1 the descent profiles of the Apollo command module, as it reentered the atmosphere, and the forthcoming Space Shuttle, now being tested for a first flight next year are compared. This figure shows range distance plotted against altitude. One can note in passing how much like a blunt lifting body the unpowered Shuttle performs in the reentry portion of its flight. Another important similarity should be noted, *viz*, both of these spacecraft have crew on board, with computers, and both have three-axis stabilization systems which permit the crew to “fly” the reentering object.

In briefly examining a mission profile of Shuttle flight it may be seen that after vertical launch, as a rocket, the vehicle jettisons its two solid outboard motors for ocean recovery, and proceeds with main engines burning to approach orbital velocity. Just prior to orbital insertion, at about 60 nautical miles, the large external fuel tank is jettisoned and that empty, crewless shell begins immediately to decelerate so that by the time it reaches 80 nautical miles altitude gravity has taken over and the tank begins to fall back into the atmosphere. The orbiter proceeds into space, completes its mission, and eventually reenters the atmosphere and comes to earth to be refitted, refurbished, and relaunched.

Looking at a typical early return pattern for a Shuttle landing on the West Coast (Figure 2), the several critical points on the ground track at which reentry actions occur may be seen. The deorbit burn is made midway across the southern Indian Ocean. The post-burn maneuver, to place the orbiter in position to encounter the atmosphere, is made while approaching Australia's west coast. Descending across Indonesia and above the Pacific Ocean the orbiter continues to fall.

The prime entry interface is at about 76 miles altitude. Communications blackout extends from about 50 miles to 25 miles and TAEM interface, that is the point at which Terminal Area Energy Management begins, occurs at about 16 miles altitude. From that altitude (about 80,000 feet) the pilot and computers carefully control and direct the rate of descent, to bring the orbiter to an unpowered landing in California at Edwards AFB, on the Mojave Desert. This same sequence is shown in a cartoon of the return profile in Figure 3.

When the final few miles of altitude are plotted in scale against the ground distance travelled, as shown in Figure 4 it is clear that functioning as a glider without power, the orbiter is actually flown down range to its predetermined landing place. From the passing of TAEM interface at 16 miles altitude, the orbiter travels about 56 miles down range to touchdown.

All of this is only to show that when we know where we are, what we are, where we are going, and how we are getting there, although without power and falling fast, we can control reentry relatively well.

Returning to that large external tank that we left falling freely after its release at 60 nautical miles altitude, it may be seen that the tank proceeds on a ballistic curve to a height of 80 nautical miles and then falls. Regardless of the angle of inclination to the equator of a Shuttle launch, the antipodal point, where or near where every east coast launched Shuttle orbit crosses, lies at about the geographical center of the Indian Ocean. External tank release is planned so that the impact point of that tank is approximately at the antipodal point in the Indian Ocean. This is shown in Figure 5. The hemispherical curve to the west of the antipodal point and the two fan-line curves to the east are the areas of possible debris impact of the surviving elements of the jettisoned external tank.

Coming to the point of all these descriptive graphics, Figure 6 must be considered. As the tank falls back into the atmosphere, at an altitude of about sixty miles the tank is tumbling and begins to heat up. First tank rupture is expected at about 50 miles and primary break-up occurs at about 45 miles altitude. Secondary break-up of debris continues and debris begins to burn up in the atmosphere below forty miles with some pieces of debris surviving to the surface.

As shown in Figure 7, the predicted external tank impact point is very close to or on the antipodal point. However, there are a number of uncertainties involved such as:

- (1) precise trajectory uncertainty,
- (2) effects of the atmosphere,
- (3) aerodynamics of the tumbling tank,
- (4) altitude at rupture and break-up,
- (5) attitude at break-up

and other technical factors such as weight and shape of debris pieces. Taking all these elements into account, knowing the size, shape, weight and direction of travel of our tank, our best ability to project impact is to identify a strip extending 868 nautical miles up range and 859 nautical miles down range, more than 1700 miles of ocean, 50 miles wide, in which the debris will fall with a high degree (greater than 97%) of certainty.

If, in contrast to this situation, one considers a space object of unknown size, weight, shape, material composition, etc. approaching the atmosphere at many thousands of miles an hour and considers that it can skip, hop or dive as it encounters the atmosphere and that it can break into many pieces and scatter over a large area, then one may have a case like the USSR's satellite Cosmos 954. Then one can understand why, on the morning on which it reentered above Canada our NASA/NORAD last best prediction was that it would enter near Hawaii and, at about the same time, the Russians were predicting reentry near the Aleutian Islands. Then one will also understand why, considering the mechanics and uncertainties of unprogrammed reentry, it is a practical impossibility to predict in advance where or when a satellite will come down, or its pieces will come down, after an unprogrammed reentry.

Figure 1

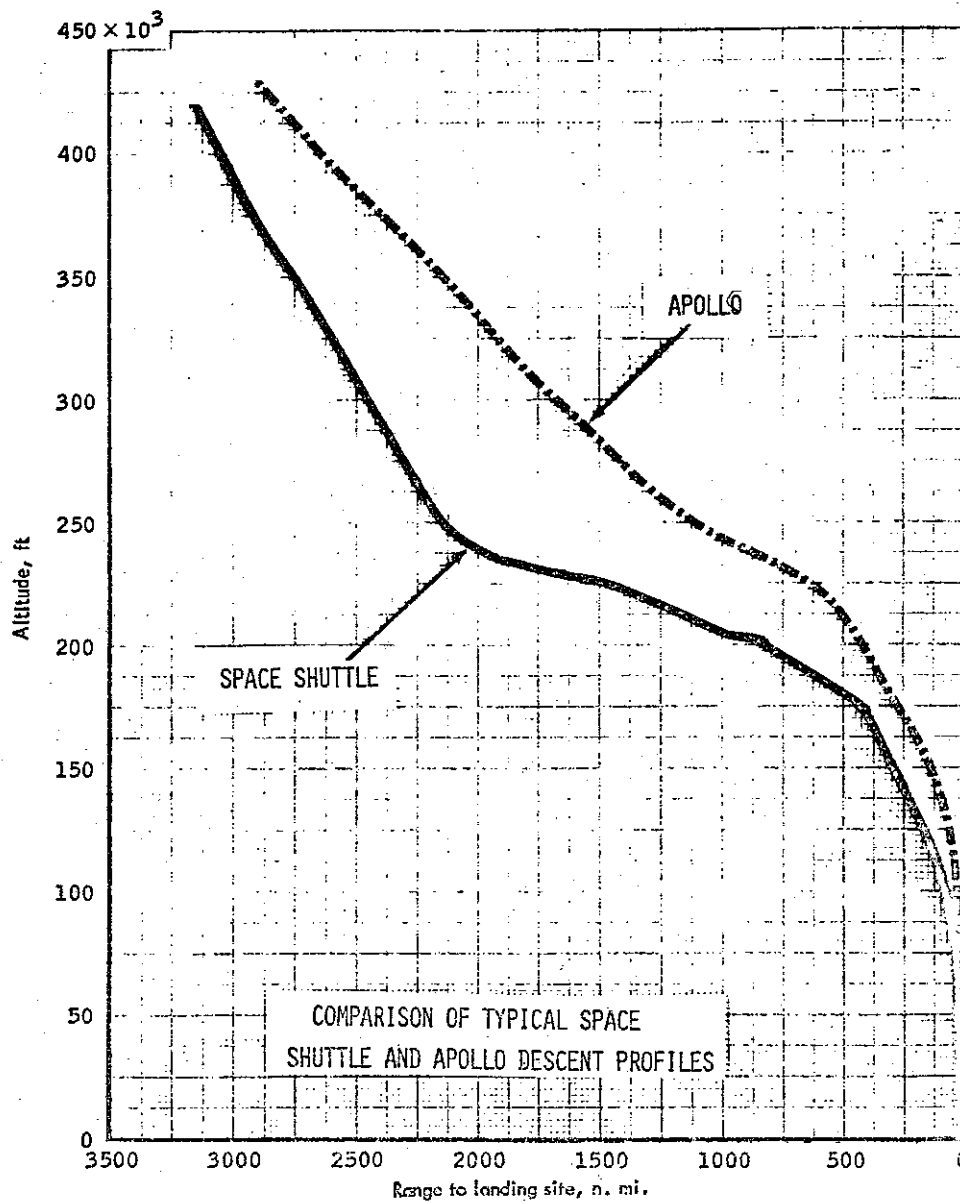
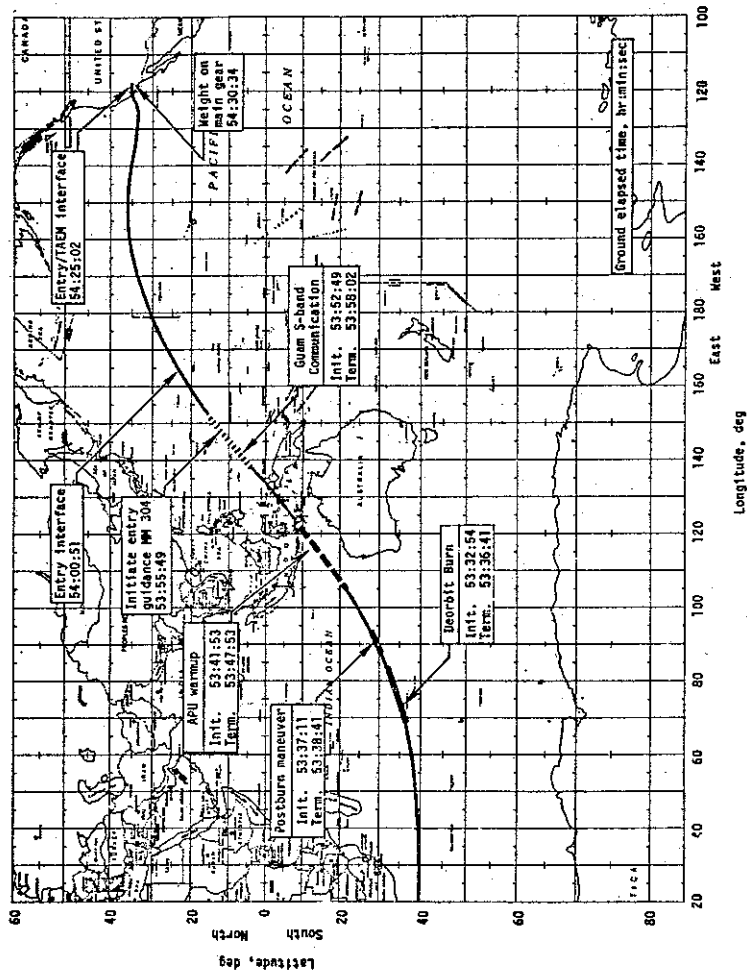


Figure 2



OFT DEORBIT-THROUGH-LANDING GROUNDTRACK

Figure 3

ENTRY FLIGHT PROFILE

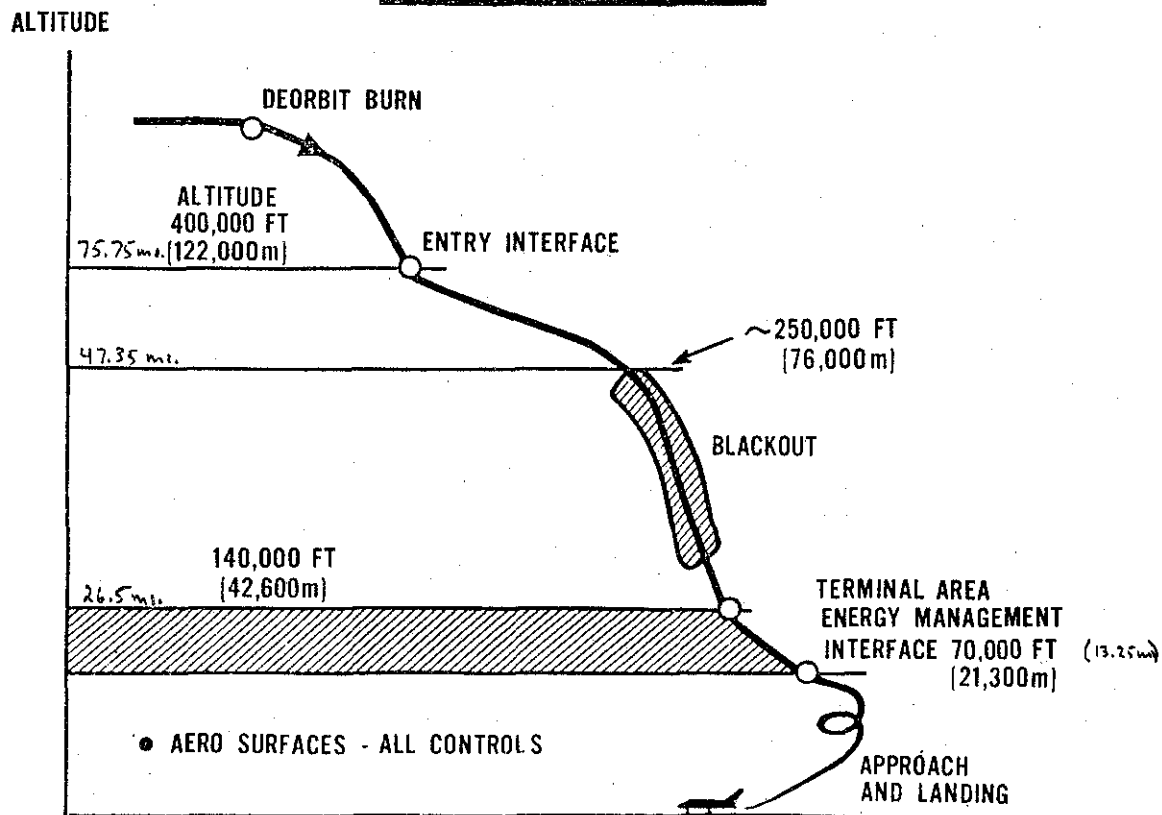
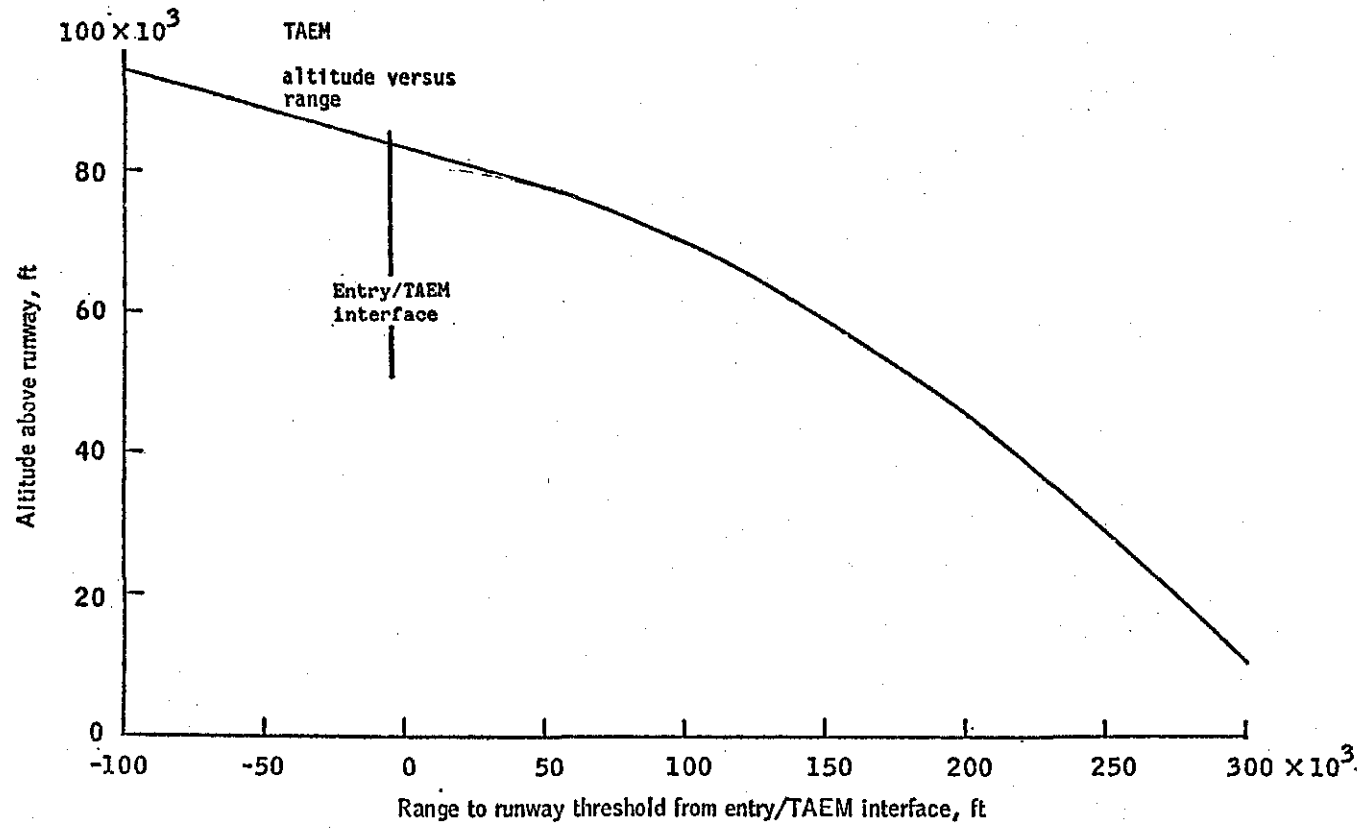


Figure 4



- Altitude versus range at entry/TAEM interface.

Figure 5

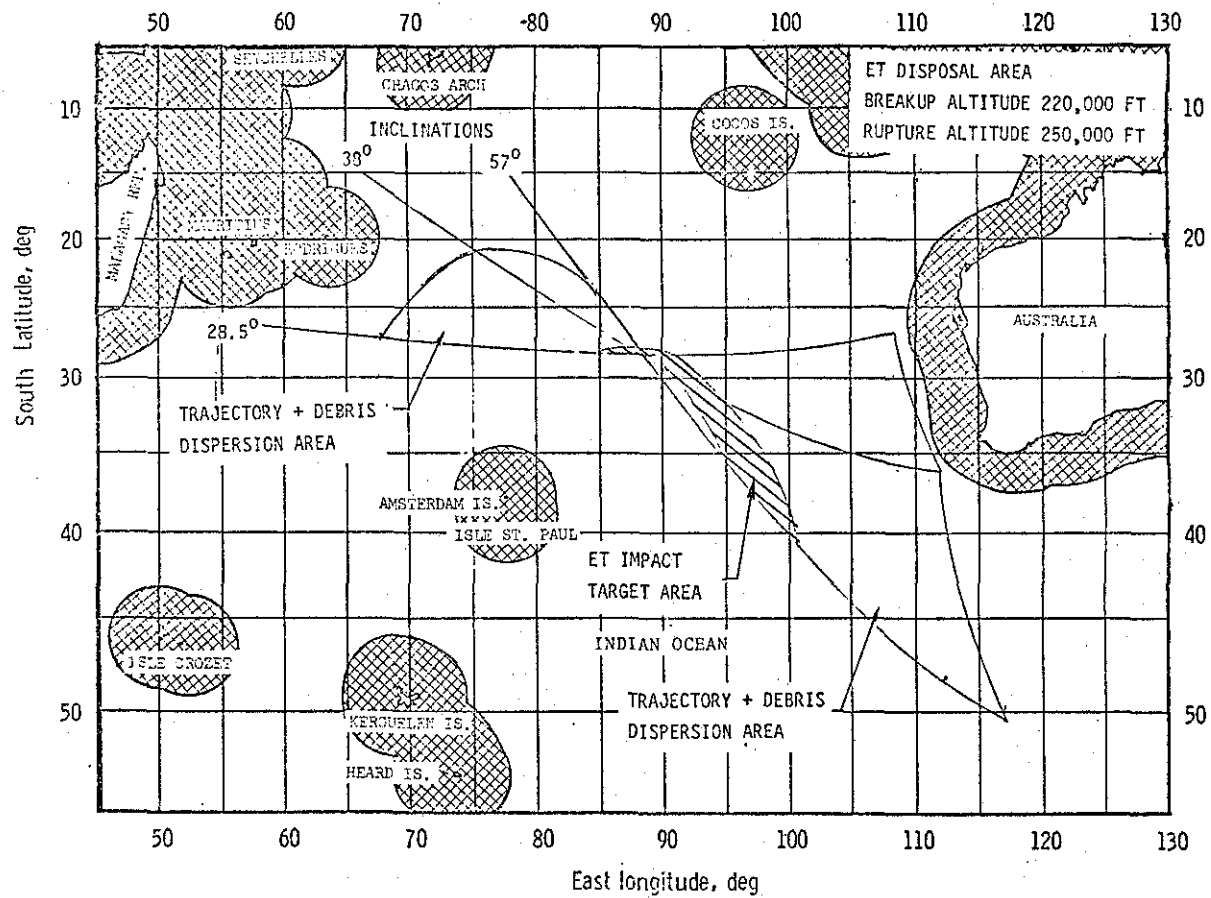


Figure 6

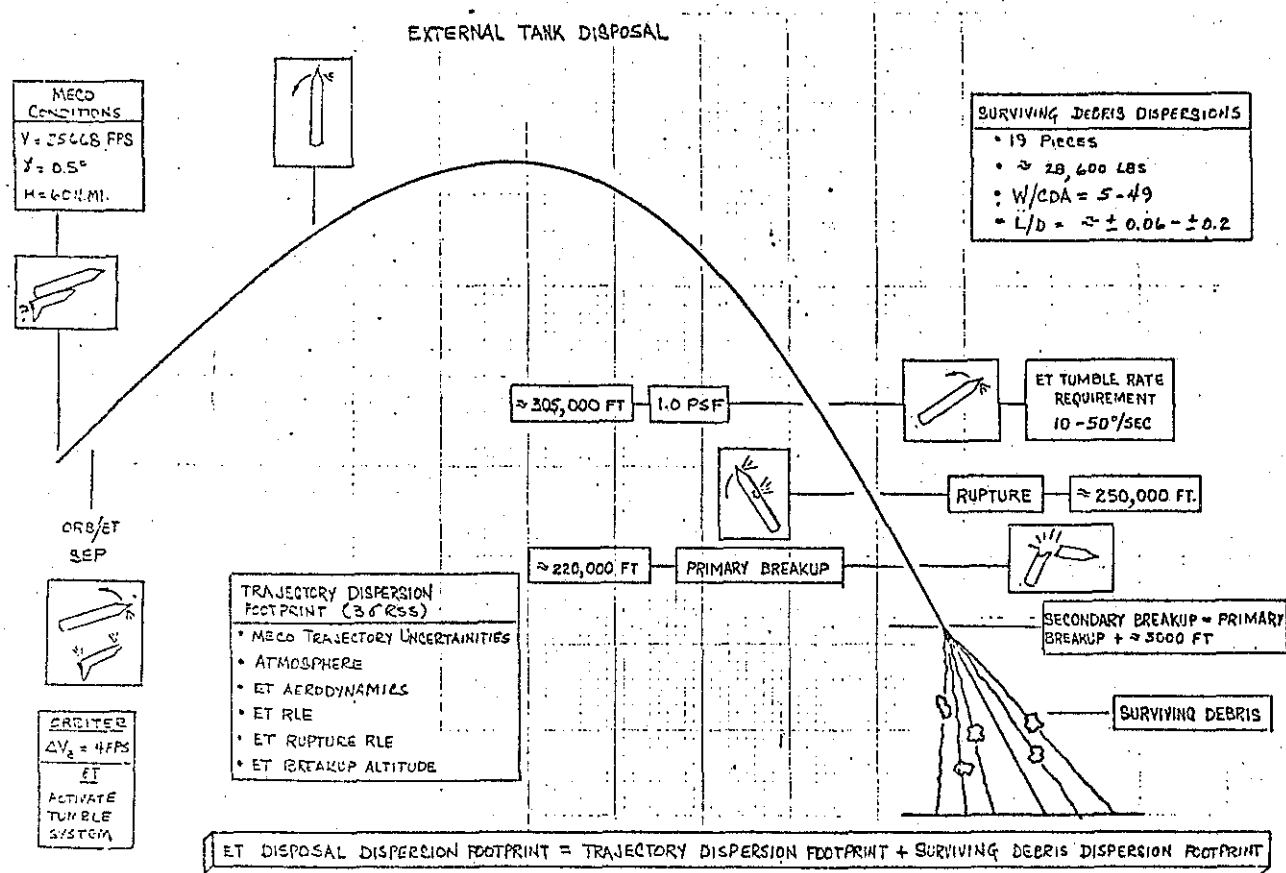
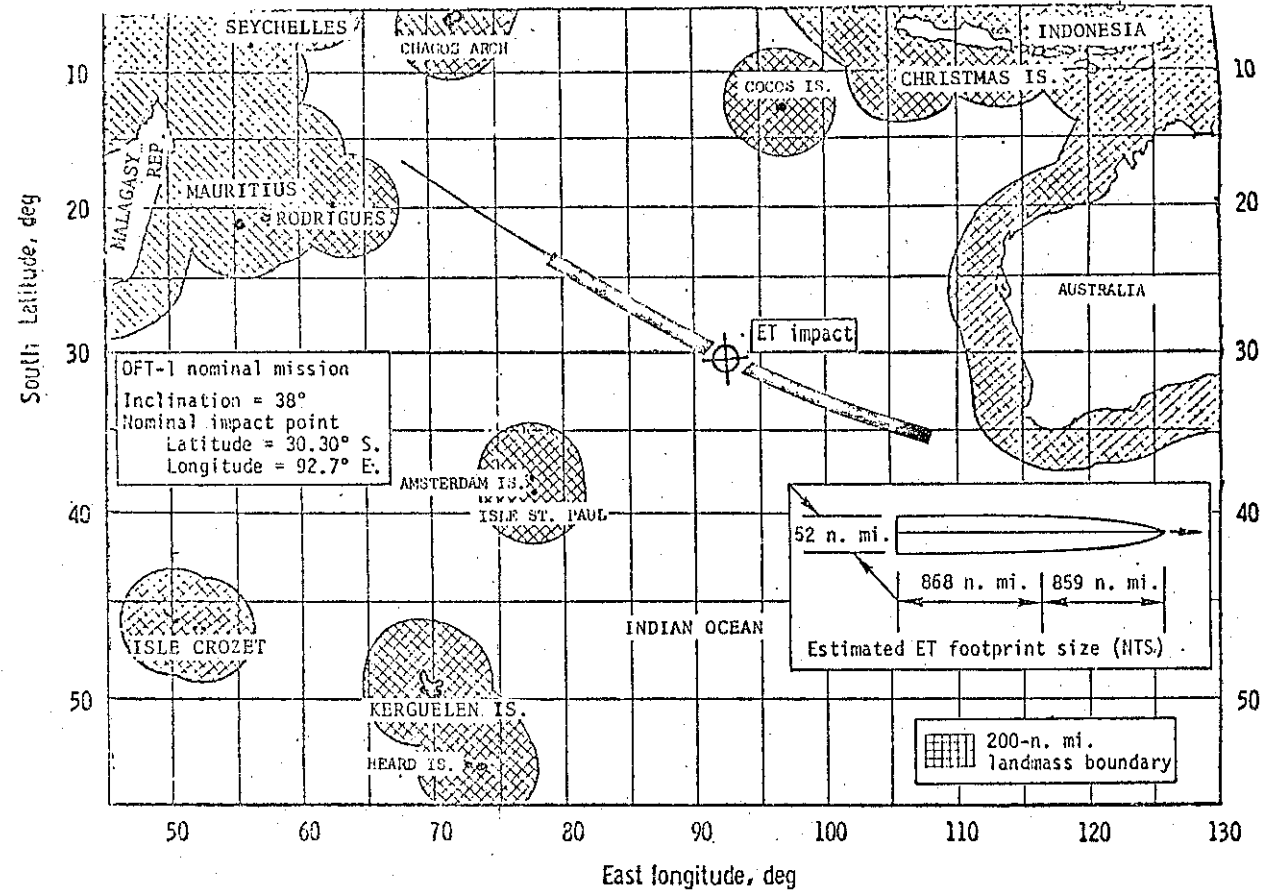


Figure 7



NOMINAL ET IMPACT AND DISPERSION AREA