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NUCLEAR POWER FOR SURFACE EFFECT VEHICLE AND AIRCRAFT PROPULSION

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ABSTRACT

Preliminary results of an economic study of large nuclear surface effect vehicles and aircraft indicate that these vehicles may have the potential for hauling transoceanic commerce at rates of 1 to 2 cents per ton mile. Transoceanic commerce forecast for 1980 indicates that it would take 1500 10,000 ton gross weight surface effects vehicles to handle all the cargo that is worth shipping at 1 to 2 cents per ton mile. Similarly, it would take 500 10,000 ton aircraft to handle this same volume.

One of the most important technical problems is the problem of safety during high speed impacts. Tests of mobile reactor models indicate a potential for withstanding impacts up to 1000 feet per second with reinforced concrete without rupturing or producing leaks in the reactor containment vessel.

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SUMMARY

Preliminary results of an economic study that indicates the potential application of nuclear surface effect vehicles and aircraft for carrying transoceanic commerce in the post 1980 time period are presented. A summary of recent encouraging mobile nuclear reactor safety experiments for high speed impacts is also presented.

The results of the economic study indicate that there would be a potential need for about 1500 nuclear surface effect vehicles of 10 000 tons gross weight with a speed of 100 knots to handle transoceanic commerce if the shipping cost would be about 1 to 2 cents per ton mile. The study indicates that nuclear powered surface effect vehicles may have the ability to carry cargo at rates less than 2 cents per ton mile. Subsonic nuclear aircraft with a gross weight of 1000 tons may be able to carry cargo at the rate of 4 to 5 cents per ton mile. Very large subsonic nuclear aircraft of the order of 10 000 tons in gross weight may be able to carry cargo at rates less than 2 cents per ton mile. It would take a fleet of 500 such aircraft to handle transoceanic trade that would be economically feasible to carry at 1 to 2 cents per ton mile in 1980.

Nuclear powered surface effect vehicles are closer to practical application than nuclear aircraft because their safety problems are trivial when compared to aircraft. The results of an experimental investigation that demonstrate techniques for the prevention of reactor containment vessel rupture during impacts with reinforced concrete at speed up to 584 feet per second are very encouraging. No leaks were detected in any of the models after impact. Analysis of the results indicates potential impacts at speeds of 1000 feet per second with no rupture.

INTRODUCTION

NASA has been conducting a low level study of large nuclear powered surface effect vehicles and aircraft. The objectives of the study are (1) to determine the feasibility of practical, safe and economical nuclear powerplants for surface effect vehicles (SEV) and aircraft; (2) to define the key problems requiring research and development; and (3) to demonstrate or develop key technology that is required for feasibility assessment.

The key problems are public acceptance (safety), long life, low weight, and low cost. The safety problem is concerned chiefly with containing fission products even during major accidents and reactor meltdown. Long life is concerned with the design of reliable reactors that will operate of the order of 10 000 hours between refuelings. This would eliminate the relatively complex refueling operation. Low weight is concerned with minimizing the weight of the nuclear powerplant so that it can fit within the weight envelope of aircraft and SEV. Low cost is concerned with how to make reactors low in cost so that they may prove to be economically feasible when used to propel surface effect vehicles or aircraft.

The purpose of this paper is (1) to present preliminary results of a simplified economic analysis that indicates the potential application of nuclear SEVs and aircraft for carrying transoceanic commerce in the post 1980 time period and (2) to present a summary of recent safety studies that indicates it may be possible to contain fission products of aircraft reactors even in major subsonic aircraft accidents.

POWERPLANT DESCRIPTION

Figure 1 shows a typical nuclear powerplant for propelling aircraft. A nuclear powerplant for surface effect vehicles is quite similar. The nuclear reactor is surrounded by containment vessel and shielding. The reactor heats a fluid such as high pressure helium which is ducted to a heat exchanger located between the combustors and compressor of a typical ducted fan engine. The ducted fan engine can then operate on the heat transferred by the heat exchanger or by the combustion of fuel in the conventional chambers. The containment vessel is designed to prevent the release of fission products even during the worst aircraft accident or reactor meltdown. The shield materials provided are designed to absorb the energy of impacts. They are also designed so that the heat generated in a reactor meltdown is uniformly distributed. The containment vessel can then be cooled by natural convection and radiation to atmospheric air without hot spots. This is important in the case of a major accident where all normal cooling systems are destroyed.

REASONS FOR INTEREST IN NUCLEAR TRANSPORTATION

Why is there interest in nuclear powered surface effect vehicles and aircraft for transportation systems in addition to traditional surface ships? One important reason is that the world is experiencing an enormous expansion in ocean borne trade. Figure 2 shows the results of a Department of Transportation study which forecasts world oceanborne cargo trade in billions of tons as a function of year (ref. 1). World trade will almost double by 1980 and quadruple by 2000. U.S. trade will double by the year 1990. Should the world handle this increase in trade merely by doubling its present ocean going fleet or should the advanced technology gained from our aerospace industry be utilized? This question is a particular importance for the United States. The U.S. is at present in a poor position to compete with the world in constructing conventional ships. Subsidies are required to maintain our maritime industry because other nations can produce ships at less than half the cost. In addition, other nations are currently producing ships that are much larger, more modern and more efficient to operate. Traditionally the U.S. can compete best in the world market when it offers products involving a high level of technology. Our commercial aircraft industry is the prime example of this.

The following are new technologies that could be considered to meet the forecasted demand for transoceanic commerce: (1) large high-speed surface ships, (2) large cargo submarines, (3) large surface effect vehicles, and (4) large aircraft. Large high-speed ships would be desirable to handle the large increase in traffic. It is possible that large cargo submarines using nuclear powerplants may offer an advantage. Submarines are more efficient than surface ships but they cost more to construct. Surface effect vehicles have the advantage of high speed than ships or submarines. They have been introduced into commercial service as ferries for carrying passengers and automobilies across the English Channel (see fig. 3). They are relatively small short-range vehicles and could not be used for ocean going travel. However, the technology appears to be in hand to build SEV's that are sufficiently large and have sufficient range to traverse the ocean. This is an area where the U.S. could contribute, particularly if nuclear power is used. (Chemical powered SEV's tend to be limited in range or payload because of the relatively large fuel consumption.) Light weight nuclear powerplants of the compact type that would be used for aircraft appear to be quite attractive for large surface effect vehicles where long range is an important feature. Large aircraft have the promise of reducing the current high cost of cargo transport by air. If the cost can be reduced sufficiently, SEVs or aircraft could conceivably take over a significant portion of transoceanic trade. If the cost of transporting cargo in cents per ton mile could be reduced to 1 or 2 cents per ton mile, then it may prove economically viable that SEVs or aircraft could capture 10 to 15 percent of the world ocean trade. (Truck and rail transportation rates are in the range of 1 to 2 cents per ton mile.) In addition the attraction of high speed may produce new business not considered in the Department of Transportation forecast.

How much of the potential cargo commerce would be captured by vehicles that could deliver cargo at a rate of 1 to 2 cents per ton mile at speed of 100-500 knots? Some statistics on U.S. foreign commerce presented in reference 2 can shed some light on this. In 1968 more than 10 percent of the total U.S. foreign commerce was liner tonnage. The average value of liner cargo was about 28 cents per pound. (Assuming that 10 to 15 percent of the value of a product can reasonably be allowed for shipping yields an allowable charge of 1 to 2 cents per ton mile for 28 cent per pound cargo delivered a distance of 4000-6000 nm.) If it is assumed that 10 percent of all world trade of 20 trillion ton miles in 1980 is liner tonnage, then about 2 trillion ton miles will be liner tonnage that can be shipped at rates of 1 to 2 cents per ton mile. At a speed of 30 knots with a cargo of 100 000 tons, payload factor of 0.6, utilization of 0.6, a single ship would have a cargo carrying capacity of about 8 billion ton miles per year. It would take 250 ships of this speed and size to handle the volume.

A surface effect vehicle (SEV) with a speed of 100 knots and cargo capacity of 5000 tons would have a capacity of about 1.3 billion ton miles per year. It would take a fleet of more than 1500 such vehicles to handle the commerce if the SEV could haul cargo at the rate of 1 to 2 cents per ton mile.

Similarly an aircraft with a speed of 500 knots and cargo capacity of 1000 tons would also have a capacity of about 1.3 billion ton miles per year. It would take a fleet of more than 1500 aircraft of this size to handle the commerce if the aircraft could haul cargo at the rate of 1 to 2 cents per ton mile.

It would appear that it is well worth looking into the possibility of SEVs or aircraft hauling cargo in the range of 1 to 2 cents per ton mile

Both fossil fueled and nuclear fueled powerplants should be considered. High speed and long range require large amounts of energy. This, of course, means large fuel requirements and fuel costs. Nuclear fuel is much cheaper than fossil fuel. Nuclear fuel is also relatively weightless since it provides about a million times more BTU's per pound than can be obtained from chemical fuel. Nuclear reactors are more attractive for large vehicles. The larger the vehicle, the smaller is the fraction of the total weight taken up by the powerplant. Nuclear powerplants tend to increase in weight as the square root of the power they produce. Conventional powerplants tend to increase in direct proportion to the power that they produce.

There are, of course, disadvantages to the use of nuclear energy. First, even though reactor fuel is relatively weightless, the reactor is heavy because it requires biological shielding. Secondly, reactor fission products must be fully contained even in the worst accidents. This containment system constitutes an additional weight. Thirdly, reactors add an additional cost factor. The machinery that changes heat energy to mechanical energy or thrust required for nuclear powerplants is basically the same as for chemical powerplants. However, a reactor is needed in place of the fuel and the fuel tanks of chemical vehicles. Since reactors tend to be relatively costly, they add additional cost to the vehicles. Hopefully, the savings in fuel cost may compensate for the higher initial cost.

A comparison of chemical and nuclear fuel costs is shown in Table 1. The unit cost of marine fuel, aviation fuel and nuclear fuel, and also the cost in dollars per millions of BTU's of these fuels is presented. Marine fuel typically costs about $2.50 a barrel. This is equivalent to about 0.39 dollars for each million BTU produced. Aviation fuel runs as low as 8 cents per gallon. This is the equivalent of 62 cents for each million BTU. Nuclear fuel costs $8 to $12 per gram of uranium 235 atoms. This amounts to about 10 to 15 cents per million BTU. Thus, nuclear fuel basically costs about 1/3 to 1/6 the cost of chemical fuel. The savings in fuel charges is available to pay for the additional cost that is incurred by using a nuclear reactor. Whether the fuel savings can compensate for the higher capital cost is one of the subjects of the present study.

RECENT RESULTS OF NASA STUDIES

Preliminary results from a cost study and also some of the results from the safety portion of NASA's nuclear surface effect vehicle and aircraft study are discussed. These two areas cover the most recent work and are of greatest interest at this time.

Simplified Cost Study

It is beyond the scope of this paper to discuss the simplified cost analysis in detail. The analysis at present is not complete and the results are preliminary. The purpose of presenting preliminary results is to point out that such a study is being made and that some interesting results appear to be forthcoming.

Factors considered. - In this study we attempt to compare ships, submarines, surface effect vehicles, and aircraft in terms of payload and speed. Nuclear and chemical power are considered. The following are some of the more important factors that were considered in the performance analysis of chemical and nuclear vehicles.

(1) Vehicle drag as function of speed
(2) Structural weight fraction
(3) Propulsion system weight & efficiency
(4) Reactor and shield weight, dose rate 0.25 mr/hr
(5) Fuel requirement as function of Breguet range
(6) Emergency chemical range for nuclear vehicles

Vehicle drag is considered as a function of speed. Generally drag is considered in terms of L/D values of which will be presented in a later section of the paper. Representative values of structural weight fraction have been assumed and can be varied. The propulsion system weight and efficiency is varied with engine type and speed. Reactor and shield weight is computed for a dose rate of 0.25 millirem per hour at 30 feet from the reactor. Because the dose falls inversely as the square of the distance, at 100 feet the dose is about 0.025 millirem per hour. It should be noted that the allowable dose rates are quite conservative. (The dose rate received by a person at 35,000 feet due to cosmic radiation is about 0.35 mrem/hr.) The fuel requirement is determined according to the Breguet range equation. Nuclear vehicles have a minimum emergency chemical range of 500 nm so that in the event of reactor shutdown the vehicle can land safely within the specified range. This range can be varied as desired.

The major factors that are considered in the cost analysis are as follows.

- Capital Costs:
    - Structure cost, $/lb
    - Propulsion system cost, $/shp
    - Reactor plus shield cost, $/MWt
- Operating Costs, $/Ton-Mile:
    - Chemical fuel
    - Uranium
    - Crew Cost
    - Depreciation
    - Maintenance
    - Insurance
    - Interest
    - Profit

There are capital costs and operating costs. The capital costs considered are structure cost in dollars per pound, propulsion system cost in dollars per pound, propulsion system cost in dollars per horsepower, and reactor plus shield cost in dollars per thermal megawatt. Operating cost is the cargo carrying cost in dollars per ton mile. It is composed of the sum of the listed items.

The following is a list of the more important assumptions that were used in computing the operating costs.

Utilization for all vehicles	0.60
Load factor for all vehicles	0.60
Structure life, hr	60 000
Machinery life, hr	30 000
Nuclear systems life, hr	40 000
Crew cost for all vehicles, $/hr	250
Interest rate, percent of total capital cost	6.0
Maintenance, percent of total capital cost	2.6 to 7.9
Insurance, percent of total capital cost	1.8
Profit, percent of total operating cost	15

Lift-to-drag ratios. - Figure 4 presents the lift-to-drag ratios that were assumed for the transportation vehicles studied as a function of speed in knots. Ships and submarines have the highest L/D because of their low speed. The L/D is over 1000 at speeds of 10 to 15 knots. It decreased more rapidly than as the inverse square of the speed. At speeds of 30 to 50 knots, the L/D is in the range of 30 or so. Submarine L/D's tend to be higher at the higher speeds because there is no wave drag to contend with. The drag is chiefly due to friction. The drag, therefore, increases as the square of the speed. Surface effect vehicles have L/D's that vary less with speed until the speed goes beyond 100 knots when L/D begins to drop rapidly. Aircraft L/D is constant with speed until very high subsonic speeds produce a drag rise due to shock wave formation. In subsonic range below the drag rise an L/D of 17 represents current practice, while 24 is the predicted future practice. These L/D's were used to compute the vehicle power requirements. With the other weight and cost assumptions, the overall performance of vehicles can be calculated in terms of cargo cost in cents per ton mile as a function of speed.

Ships and submarines. - Figure 5 presents the calculated performance for ships and submarines which have gross weight of 100 000 tons. The total operating costs in dollars per ton mile is shown as a function of speed in knots. The two solid lines are for chemical ships and the shaded curves are for nuclear ships and nuclear submarines. Chemical submarines were not considered because they require air for operation. Nuclear ships yield better performance than chemical ships particularly for speeds above 25 knots. At speeds above 40-45 knots, the operating costs of ships start to increase rapidly because of the high drag rise. Nuclear submarines show a rapid cost rise in the vicinity of 60 to 70 knots. However, both nuclear submarines and nuclear ships indicate operating costs of less than 0.2 cents per ton mile at speeds of 30 knots and better. The low cost, of course, is due to the low cost of building ships in dollars per pound of structure. In addition, because of the low speed, ships have low power requirements which is reflected in the low powerplant costs. Ships are truely an economical means for transportation. However, they appear to be limited economically to speeds less than about 45 knots. Submarines appear to have good economical potential for speeds in the vicinity of 60 knots or greater.

Surface effect vehicles. - Figure 6 gives the preliminary results of the operating cost study for 10 000 ton surface effect vehicles. The total operating cost in dollars per ton mile is shown as a function of speed in knots. Chemical SEVs are shown by the solid lines for ranges of 2000, 4000, and 6000 miles. The performance of the nuclear vehicle is independent of range. Surface effect vehicles are well suited for transportation in the vicinity of 100 knots and perhaps higher. The nuclear SEV shows operating costs in the range of 1 to 2 cents per ton mile. Chemical systems operate in the range of 2 to 4 cents per ton miles for transoceanic (4000 nm or greater) ranges.

The SEV increases the cargo transportation speed range from 15-30 knots of the best of today's ships to the 100 knot range. It appears possible to attain the 1 to 2 cents per ton mile operating cost if nuclear power is used.

As mentioned previously, NASA has been conducting a low level study of large nuclear powered surface effect vehicles and aircraft. The key problems are public acceptance (safety), long life, low weight and low cost. The safety problem is concerned chiefly with containing fission products even during major accidents and reactor meltdown. Long life is concerned with the design of reliable reactors that will operate of the order of 10 000 hours between refuelings. This would eliminate the relatively complex refueling operation. Low weight is concerned with minimizing the weight of the nuclear powerplant so that it can fit within the weight envelope of aircraft and SEV. Low cost is concerned with how to make reactors low in cost so that they may prove to be economically feasible when used to propel surface effect vehicles or aircraft. It would take a fleet of about 1500 10 000-ton SEVs to handle 10 percent of the world trade in 1980. Ten percent is assumed to be the function of world trade that could be shipped. These figures do not reflect the additional cargo traffic that might be attracted by the higher speed transportation system.

Nuclear aircraft. - Figure 7 shows the total operating cost for chemical and nuclear aircraft with a gross weight of 1000 tons. Chemical aircraft performance is indicated by solid lines for ranges of 2000, 4000, and 6000 nautical miles. Nuclear aircraft performance is shown by the shaded areas for assumed reactor costs of 10 000 to 20 000 dollars per megawatt. (Current land based nuclear steam generators including bulky containment vand safety systems cost about $11,000 per thermal megawatt.) The nuclear airplane can carry cargo for a cost of 4 to 5 cents per ton mile at speeds of 400 to 450 knots. For ranges 5000 nautical miles or higher, the nuclear aircraft can haul cargo at a lower cost than the chemical aircraft for the particular assumptions used in the preparation of this figure.

Figure 8 shows the effect of increasing the aircraft gross weight to 10 000 tons. A very noticeable reduction in operating cost is noted. This reduction is due to lower unit costs of airframe of larger sizes and for nuclear aircraft the lower fraction of gross weight required for shielding. The 10 000 ton nuclear airplane is competitive with chemical airplanes for ranges of less than 2000 miles. The operating cost is of the order of 1 to 2 cents a ton mile at speeds up to 500 knots. As previously stated, rates such as these are typical of rail and truck transportation. The transoceanic commerce that could be attracted by such a transportation system if it were developed would require a fleet of about 500 10 000-ton aircraft in 1980 and 1000 by the year 2000. In addition, the attraction of speeds ten times that for ships may attract subtantial additional demand that is not accounted for in the trade forecast.

Recent Safety Studies

For the past several years various concepts have been studied for safely impacting reactor systems at high speeds such as could occur in major aircraft accidents. References 3 and 4 discuss this work. During the early phases of this study impact systems employing energy absorbing frangible tubes were investigated (ref. 5). They were found to be limited to providing impact protection for impact speeds up to 300 to 400 feet per second. Recently another approach utilizing the energy absorption capability of plastically deforming shells has shown promise for impact protection up to 1000 feet per second. The first NASA studies of this technique are published in references 6 to 8. Work has begun on the problem of loss-of-reactor-coolant and afterheat removal in the event of a major aircraft accident.

Figure 9 shows the reactor containment concept that is being investigated at present. The reactor core is surrounded by shield material that is formed into geometrical shapes that act as energy absorbing material. The gamma shielding, which is typically a heavy metal such as depleted uranium, would be made in the form of a honeycomb or some similar shape that would absorb energy on impact by deformation. Water is used as a neutron shield material. The water will also serve to absorb energy because the high hydraulic pressure generated during impact causes the containment vessel to stretch and thereby absorb energy. The containment vessel is made of a ductile high strength material. It absorbs the energy as it is plastically deformed during impact. Surrounding the energy absorbing containment vessel is an energy absorbing neutron shield. It can be envisioned as a plastic material formed so that on impact the deformation and plastic flow of this material will absorb some of the kinetic energy of the reactor system.

Uranium dioxide in the form of a layer of granular particles is placed on the inside of the containment vessel and reactor vessel. The uranium dioxide acts as an insulating material that causes the reactor core material to meltdown in the event of a major accident which destroys all normal reactor cooling systems. Core meltdown and the flow of heat to the containment vessel surface causes the decaying fission product heat sources to be uniformly distributed throughout the inside of the containment vessel by vapor transport. Vapor transport from the molten material tends to cause vapors to condense in uniform concentric shells in the uranium dioxide insulation bed. This in turn tends to provide a relatively uniform heat flux to the outside of the containment vessel. The heat flux must be fairly uniform in order that the containment vessel can be cooled by convection and radiation to the atmosphere. The containment vessel is made large enough so that its temperature will stay within the limits of the strength of the containment vessel material. The uranium dioxide granules, besides providing this insulation, is also a good gamma shield.

Two experimental programs aimed at demonstrating that these containment principles work are being carried out.

Meltdown experiment. - The first is a reactor meltdown containment experiment (fig. 10). It is a test of a reactor model within a containment vessel containing uranium dioxide insulating material. The model is five inches in outside diameter. The reactor model contains molybdenum uranium dioxide fuel pins. Fission heating will cause the fuel to melt.

The containment vessel is designed to operate at a temperature of the order of 1300° to 1400° F. When the fuel material melts, it is predicted that the fuel and fission products will be redistributed in layers as they condense within the insulating uranium dioxide particles. Calculations indicate that the containment vessel will not melt through. The first model is under construction, and will be inserted in the Plum Brook reactor in late spring of 1971.

Impact tests. - A schematic drawing that describes the models that are being used to demonstrate the newest impact energy absorption principles is shown in figure 11. The containment vessel is formed of a ductile, high strength material so that when deflection occurs, plastic flow absorbs kinetic energy. The containment vessel is surrounded by an energy absorbing neutron shield material such as a plastic honeycomb. The reactor vessel model is located in the center. In the first tests, an iron ball was used to simulate the reactor. Between the reactor vessel and the containment vessel, there is an inner shield and energy absorber. This inner shield material would be fabricated of depleted uranium pieces in the real reactor. In the test models, steel was used in place of uranium for economy reasons. These models are impacted with a concrete block at speeds of about 400 feet per second. Figure 12 shows the test setup that is being used. The impact model shown is 2 feet in diameter. It is mounted on a styrofoam block between the rails of a rocket sled facility. The rockets accelerate the 4.5 foot cube concrete block that weighs 7-1/2 tons to the desired impact speed. Surplus 5 inch HVAR rockets are used to accelerate the concrete block. The case in front of the block serves to catch the ball after impact. High speed motion pictures are taken during the impact. A motion picture that summarizes the test results is available from Lewis Research Center. Figure 13 is a sequence of frames from this motion picture illustrating the impact of a model at 413 feet per second. The large amount of deflection that the containment vessel undergoes is readily visible. Figure 14 taken after the impact shows this more clearly. This vessel was leak tested after the test. No leaks were found. In other words, no fission products could have escaped had there been fission products within this vessel. The results of this test and a previous test are reported in reference 8. The amount of plastic deformation that occurred was less than 1/4 of that which the material could take before failure. It is anticipated, therefore, that this model could have survived an impact of more than four times the energy (twice the velocity) or more than 800 feet per second.

In the third test a misfire occurred that allowed the model to escape from the cage after impact with the concrete. The secondary impacts due to bounding along the countryside and destroying a utility stanchion along side the track was shown to be of no consequence as far as damaging the containment vessel was concerned. Figure 15 shows a picture of this model after the test indicating that the secondary bounces merely scratched the surface. The primary impact at about 260 feet per second flattened one side.

These tests are continuing at increasing higher impact speeds. A total of five models have been impacted. No leaks occurred in any of them. The highest impact velocity was 584 feet per second. It appears from the preliminary measurements of the deformations that occurred that models of this type should be able to withstand impacts of 1000 feet per second. It is anticipated that we will be able to design impact systems that will contain fission products up to speeds of 1000 feet per second (600 mph).

CONCLUDING REMARKS

Nuclear powered surface effect vehicles or aircraft are a potential way for the United States to enter into the competition of providing means for hauling the vast increase in ocean trade that is anticipated in the next 10 to 20 years.

Preliminary results from a simplified cost study indicate that nuclear surface effect vehicles may have the potential for carrying cargo at rates of 1 to 2 cents per ton mile. It would require about 1500 vehicles with a gross weight of 10 000 tons and a speed of 100 knots to handle the cargo that would be worthwhile shipping at 1 to 2 cents per ton mile in 1980. Subsonic nuclear aircraft or chemical aircraft with a range of 5000 nm with a gross weight of 1000 tons may be able to carry cargo at a rate of 4 to 5 cents per ton mile. Very large nuclear aircraft of the order of 10 000 tons in gross weight may be able to carry cargo at the rate of 1 to 2 cents per ton mile. It would take a fleet of 500 of such aircraft to handle the forecast trade in 1980.

A major obstacle to the successful achievement of practical nuclear powered aircraft is the problem of containing radioactive fission products during a major high speed aircraft accident. An experimental investigation of techniques for prevention of reactor containment vessel rupture during impact has shown very encouraging first results. Models have been successfully impacted at speeds up to 584 feet per second with no post-impact leaks in the containment vessel. Analysis of the experimental data indicate a potential of impacts at speeds of 1000 feet per second without vessel rupture.

The safety problems of reactors for surface effect vehicles are trivial compared to aircraft. Nuclear powered surface effect vehicles are, therefore, potentially much closer to practical application. The experience gained in design construction and operation of large nuclear powered surface effect vehicles would pave the way for very large nuclear aircraft if they continue to appear economically sound as the safety problems are solved.

The preliminary results of this simple and preliminary cost analysis indicate that nuclear surface effect vehicles should be considered more carefully to verify the apparent good economical performance predicted by this simple study.

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Table I. - Chemical and nuclear fuel cost.

	UNIT COST	$\$/10^6$ BTU
MARINE FUEL	$2.50/BBL	0.39
AVIATION FUEL	8¢/GAL	.62
NUCLEAR FUEL	8-12 $/GM	0.10-0.16

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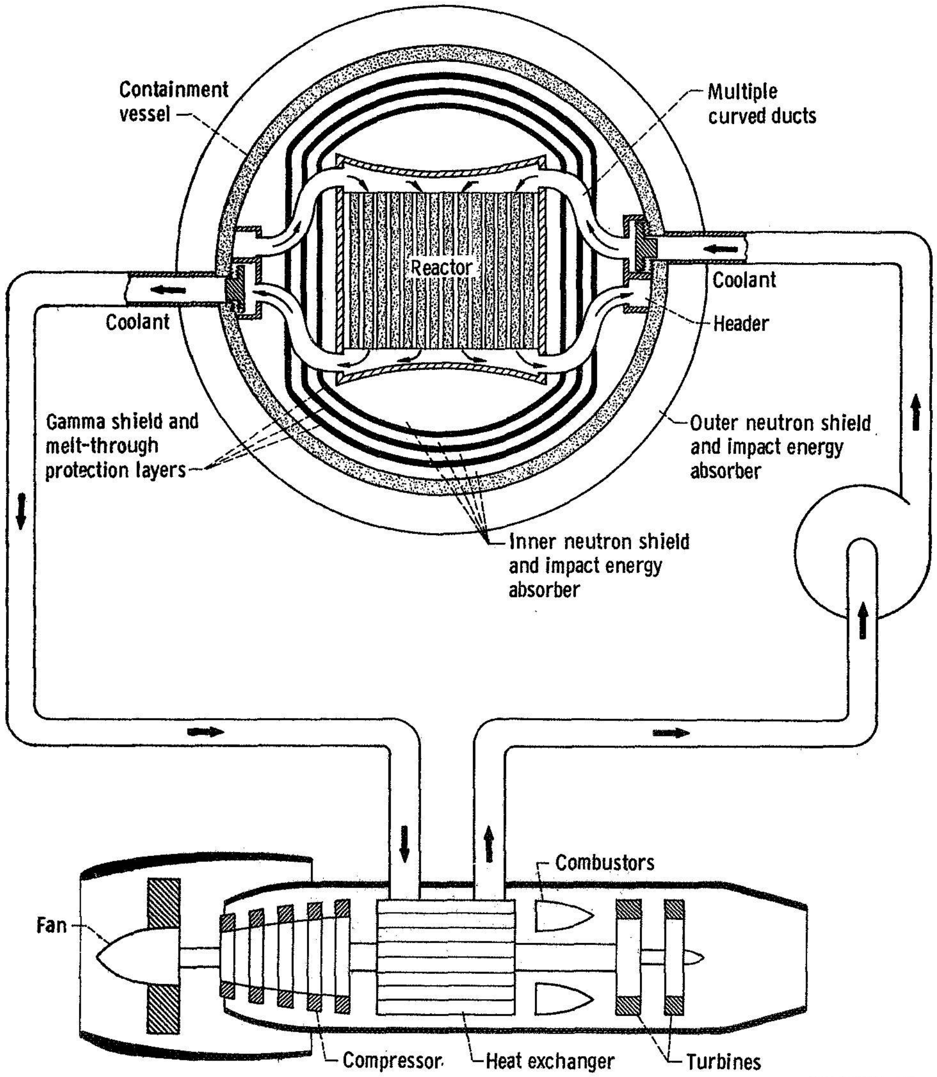

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Figure 1. - Schematic drawing of a nuclear aircraft powerplant.

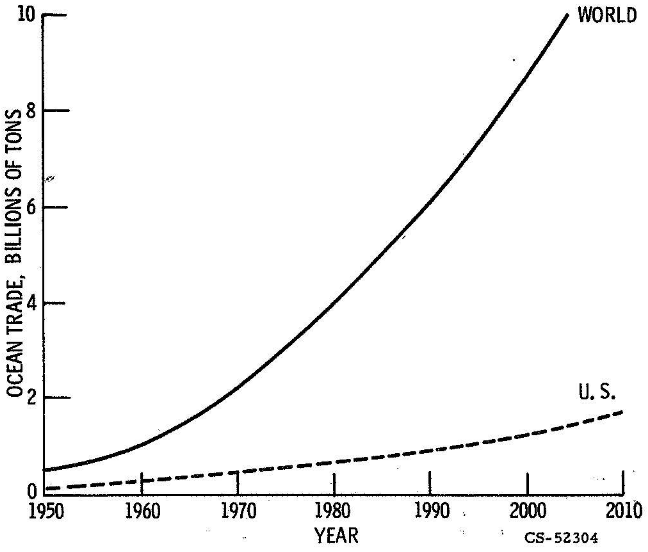

Figure 2. - Department of Transportation World Oceanborne Trade Forecast.

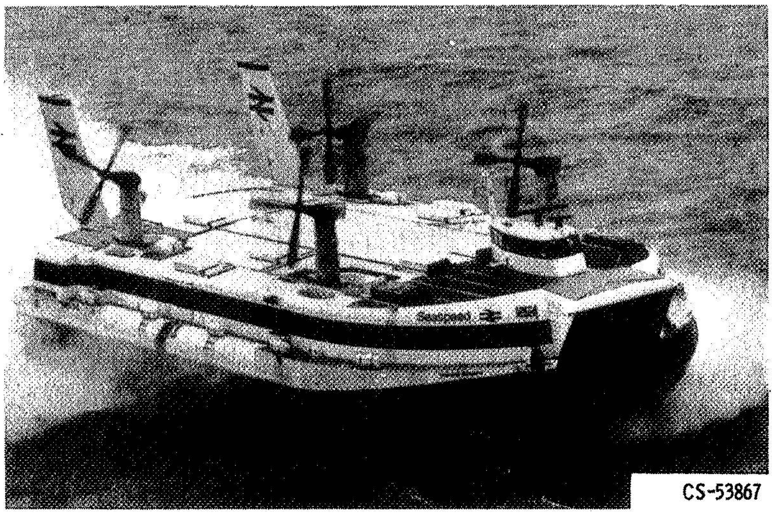

Figure 3. - British Hovercraft Ltd. SRN-4 Air Cushion Vehicle in operation as English Channel passenger and auto ferry. Gross weight, 168 tons. Speed, 65 knots.

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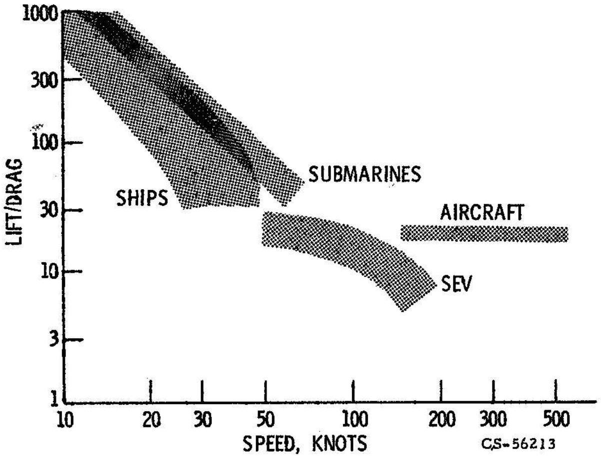


Figure 4. - Lift-to-drag ratios for transportation vehicles.

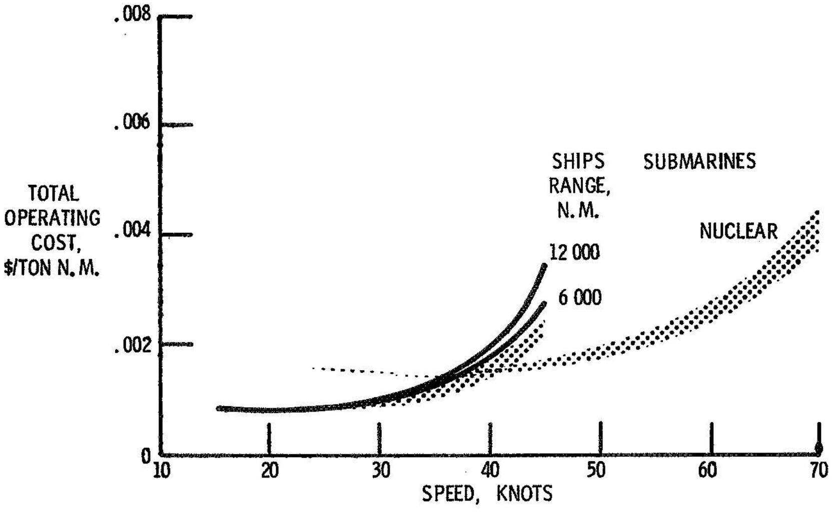


Figure 5. - Total operating cost for chemical and nuclear powered ships and nuclear powered submarines. Gross weight, 100 000 tons.

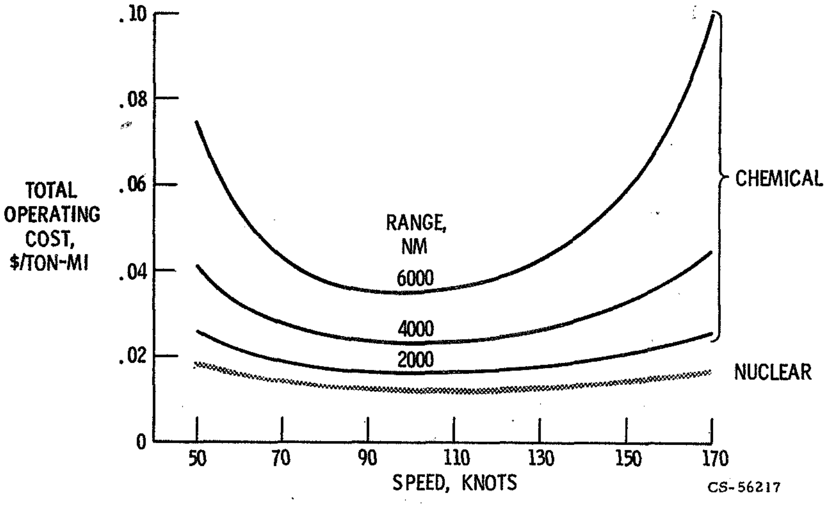


Figure 6. - Total operating cost of chemical and nuclear powered surface effect vehicles (SEV). Gross weight, 10,000 tons.

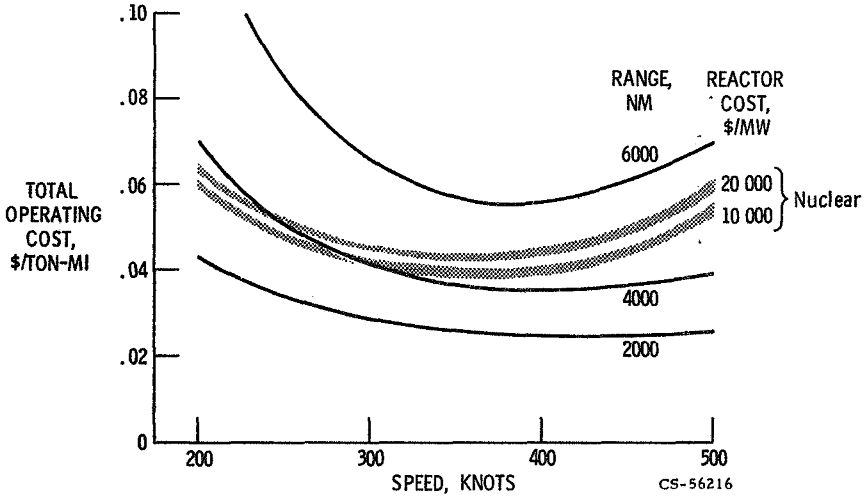


Figure 7. - Total operating cost as a function of speed for chemical and nuclear aircraft. Gross weight, 1,000 tons. Load factor, 0.6; Utilization, 0.6.

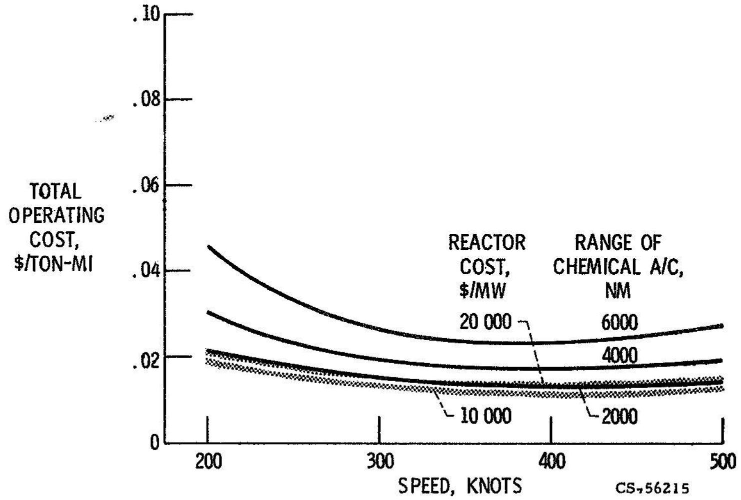


Figure 8. - Total operating cost as a function of speed for chemical and nuclear aircraft. Gross weight, 10,000 tons; load factor, 0.6; utilization, 0.6.

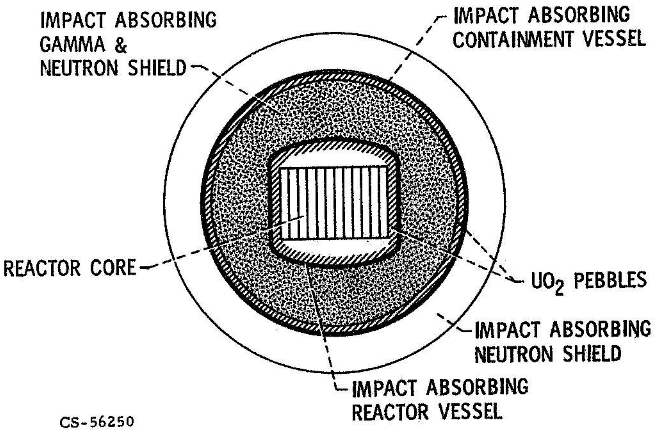
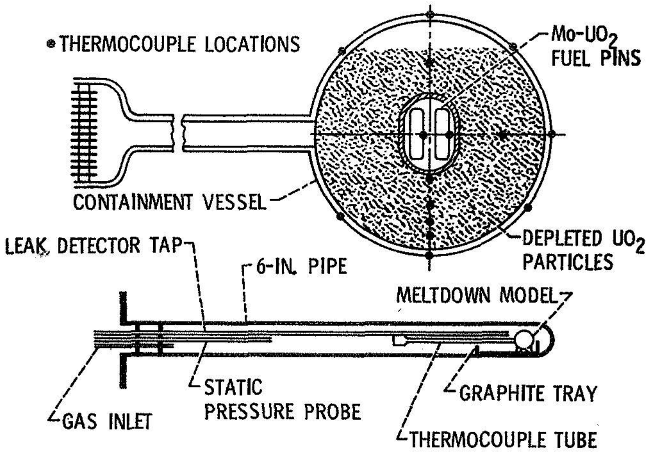
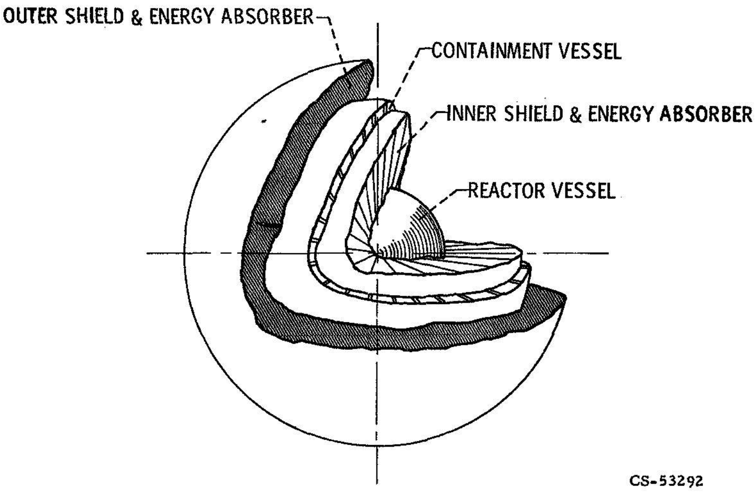


Figure 9. - Mobile reactor containment system concept.



CS-53861

Figure 10. - Reactor meltdown containment experiment.



CS-53292

Figure 11. - Schematic drawing of impact models.

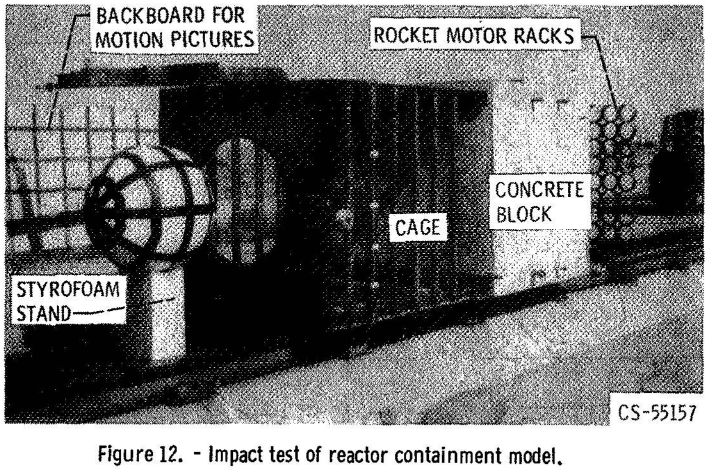


Figure 12. - Impact test of reactor containment model.

E-6163

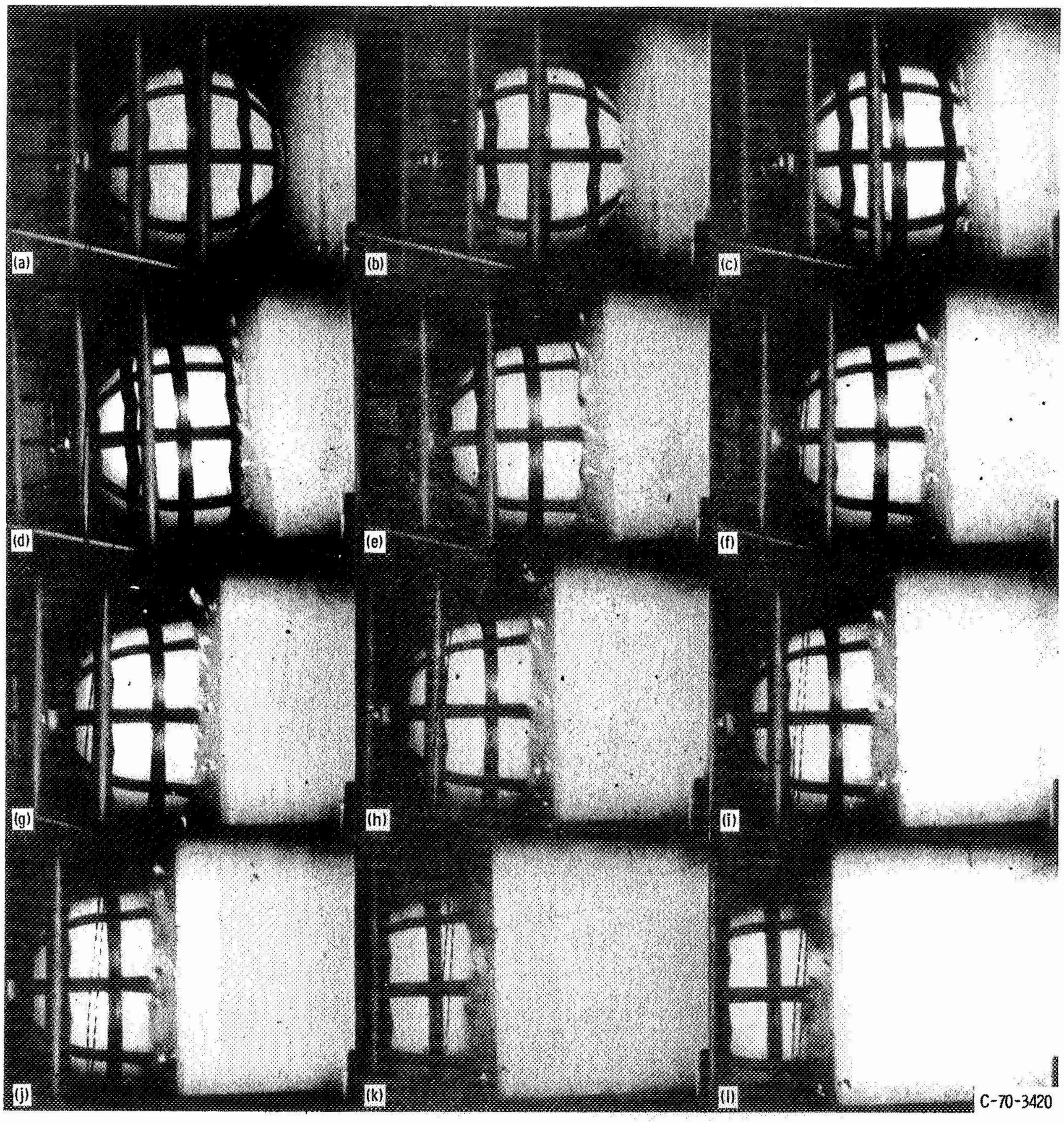


Figure 13. - Scenes from impact of two foot containment vessel at 413 ft/sec.

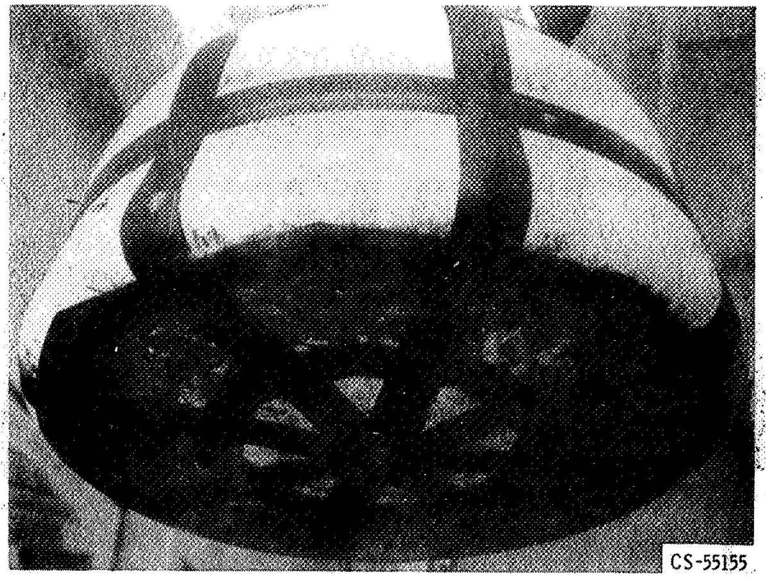

CS-55155

Figure 14. - Post-impact photo of model impacted at 413 ft/sec.

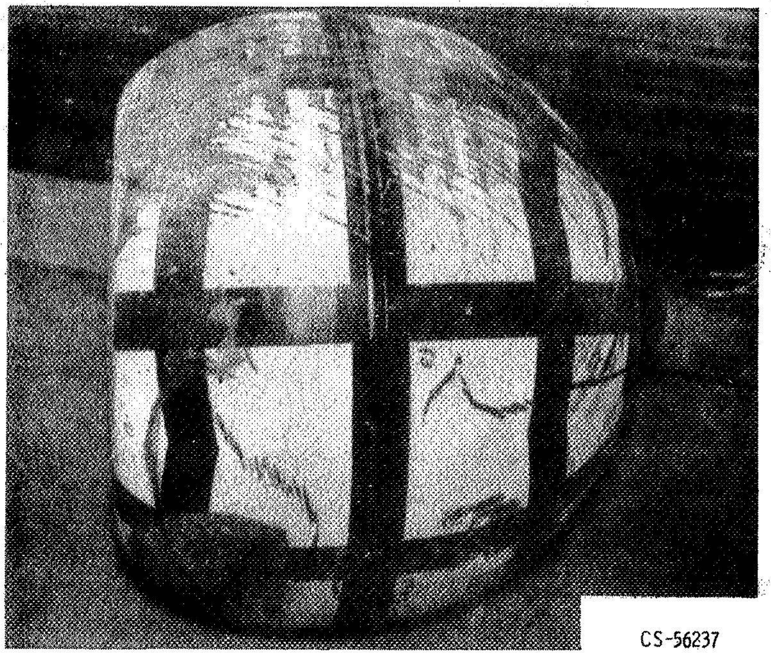

CS-56237

Figure 15. - Impact model after impact at 260 ft/sec showing scrapes of minor nature that occurred when the model escaped from the catcher cage and bounced along the track and country side until it stopped.

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