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CONTRIBUTIONS OF FREE-FLIGHT MODEL TESTING TO THE DEVELOPMENT OF BOOST-GLIDE VEHICLES

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INTRODUCTION

During the last fifteen years, with the advancement of the ballistic missiles, rocket-boosted test vehicles using mostly solid propellants have achieved great capabilities. The primary purpose of the development of these rocket-powered test vehicles was for vertical probes. At the present time these test vehicles have attained a capability of probing into great altitudes, several thousands of miles up, at velocities beyond the earth-orbiting velocity. In combination with other available missile boosters, solid or liquid, these test vehicles can probe into the deep space at velocities exceeding the earth escape velocity.

In the development of lifting boost-glide and reentry vehicles, it is desirable to conduct some free-flight tests with these test vehicles. The question has often been asked what can be gained by these tests that can not be obtained from other ground experiments or tests. It is the purpose of this paper to critically examine the capability of presently available test vehicles, their major contributions to the development of lift boost-glide reentry vehicles, and the problems remaining to be solved before free-flight tests can be reasonably assured of success.

CAPABILITY OF AVAILABLE TEST ROCKETS

Table I shows the capability of presently available rocket-powered test vehicles, their maximum payload and maximum attainable velocity. These rocket-powered test vehicles were primarily developed for probing the geophysical and gasdynamic environments. The requirements here are simply velocity, altitude, and reasonable payload capability for instrumentation. Their trajectories are mostly near vertical ballistic trajectories except those for the "over the top" firings at the NASA Wallops Station. But the requirement for lifting boost-glide testing is for a small reentry angle or near horizontal attitude at burnout for larger payloads. The NASA Scout and the Air Force Hyper Environment

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Testing System (609A) are designed for this mission. The 609A and the Scout can send a payload of about 150 pounds into a 300-mile orbit and can carry much heavier payloads at suborbital velocities. Figure 1 shows the Scout or the 609A payload capability superimposed on a familiar flight corridor chart. It is seen that the Scout or the 609A vehicle is able to reach the critical heating region within the corridor at velocities between 18,000 and 22,000 feet per second with a substantial payload. The X-15 and X-17 capabilities are also indicated for comparison. The X-17 points are, of course, the maximum velocity at those altitudes on its ballistic trajectory. It is important to note that the major modification to the basic Scout is for the strengthening of the rocket casing and interstages and the stabilization of the last stages compatible with winged lifting reentry models.

LIMITATIONS OF GROUND TEST FACILITIES

Much of the present lifting reentry glider design is based on theoretical analyses and extrapolations which necessitate the employment of certain assumptions. Whenever there are assumptions, there are uncertainties. These uncertainties must be cleared up and the assumptions must be verified by experiments before a sound design can be achieved. Many experiments in the hypersonic regime have been conducted in ground facilities but these ground test facilities have limitations.

Present hypersonic wind tunnels are often limited in the Mach number and Reynolds number ranges due to the nozzle construction and physical plant. Shock tube, shock tunnel, and arc-heated tunnels all have similar limitations. Their temperature and pressure environments are quite satisfactory but the true environments encountered in actual flight are rarely simulated simultaneously. The chemical state of the gas in a test facility before and after the shock wave is beyond the control of the facility operators. Furthermore, the ground facilities are usually small; they can accommodate only small-scale models. This not only creates serious scaling problems but the data obtainable are also limited. It is therefore concluded that the present hypersonic ground test facilities can furnish some qualitative information or trends but are certainly not sufficient to produce truely simulated design data for the entire Mach and Reynolds number ranges. In figure 1 it was shown that a free-flight test vehicle can boost a model to the desired velocity and altitude and that the model will fly under the exact environments along its own glide path.

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DATA FROM FREE-FLIGHT MODEL TESTS

From free-flight model tests the following data are obtained: tracking and accelerometer, pressure and skin friction, heat transfer and temperature, control effectiveness, survival of structures and materials, and the effectiveness of the cooling methods - namely, radiation, internal radiation, internal fluid cooling, film cooling, and ablation. It should be pointed out that these tests should not be treated as scaled model tests in the usual manner because of the model scaling problems involved. They provide local information on flow conditions and verification of theoretical predictions and design concepts.

CONTRIBUTIONS OF FREE-FLIGHT MODEL TESTS

The contribution of free-flight model tests can be described in two categories: (1) The comparison of different configurations and design concepts derived from the overall performances and (2) The increase of the degree of confidence of analytical methods from the local data. The comparative testing will result in a better selection of configuration and design concept, whereas the local data will aid in the removal of the uncertainties in the establishment of a reliable analytical design procedure as to the chemical state of the gas, the low density effects, and the interference effects.

Figure 2 shows the estimated region of flow conditions from theoretical studies made at the Flight Science Laboratory, AVCO, and the Wright Air Development Division Aircraft Laboratory. The dividing boundaries lie in the most critical region of the equilibrium flight corridor of a lifting reentry vehicle. If any confirmation of these theoretical studies can be obtained in determining more accurately the state of the flow, these tests will contribute greatly to the development of boost-glide reentry vehicles through the removal of many of the uncertainties. Even when the exterior configuration is decided, this information is still needed to finalize the detailed design.

PROBLEMS

Free-flight model testing still has some unsolved problems. The ground tracking and model-survival information can be obtained without data transmission. But, it is certainly most desirable to have both telemetered data and recovered records for all other information. The ionized sheath is known to cause considerable attenuation on standard

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telemetering. However, many programs are in progress for the development in this area of means to overcome this difficulty and the Atlantic missile range already has higher frequency equipment in operation.

Model scaling is a basic problem in the theory of dynamic similitude. The NASA, the University of Minnesota, and other laboratories have studied this problem for some time. The general conclusion is to recommend to test full scale especially when some structural data are desired. If the objectives of a free-flight test are aimed at the verification of a design method or the comparison of design concepts and configurations, the model scaling difficulty becomes of secondary importance since the primary objective is to compare the test data with the design method of the test model itself without reference to any prototype vehicles. Consequently, the real problem is the design of the experiments. One must efficiently design the model, the sensors, and the instrumentation to give maximum useful information within the capability of the test vehicle.

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CONCLUDING REMARKS

Test vehicles such as the Scout and system 609A are available now at relatively low cost. It is even more economical by incorporating many experiments in a single firing. The application of these test vehicles yielding information to verify the design analyses, structural concepts, and material application would contribute greatly towards better design as well as to the progress of present and future generations of lifting hypervelocity and reentry vehicles.

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TABLE I.- CAPABILITY OF SEVERAL ROCKET-POWERED TEST VEHICLES

Rocket	Maximum velocity, ft/sec, of vehicle with payload of -				
	15 lb	50 lb	150 lb	500 lb	800 lb
HTV-1	7,000				
HTV-2	12,000				
HTV-3	16,000				
Jason		13,500			
Javelin		15,000	13,000		
Journeyman		22,000			
Aerobee-Hi			7,000		
Nike-Cajon		5,700			
Exos		10,000			
X-17			13,000 to	7,000	
Scout and 609A			30,000; orbiting	20,000	17,000

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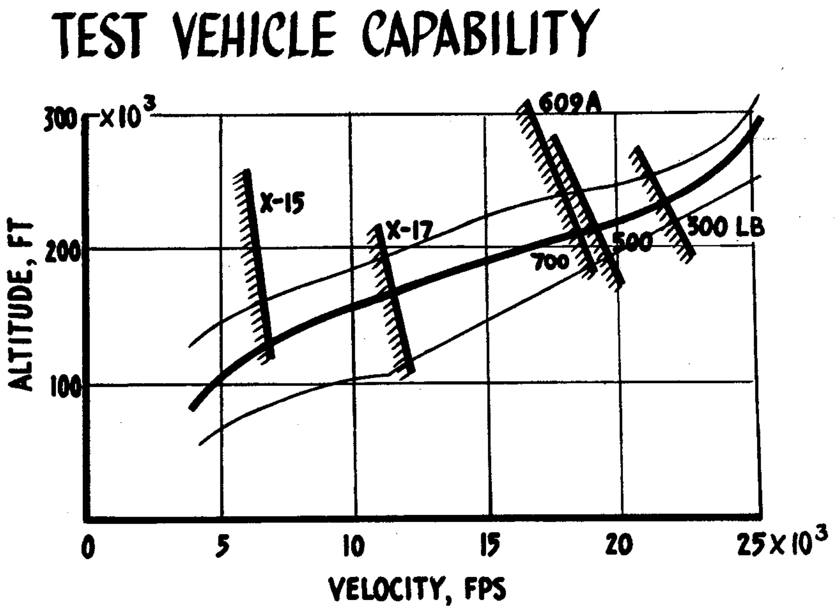
TEST VEHICLE CAPABILITY

Figure 1

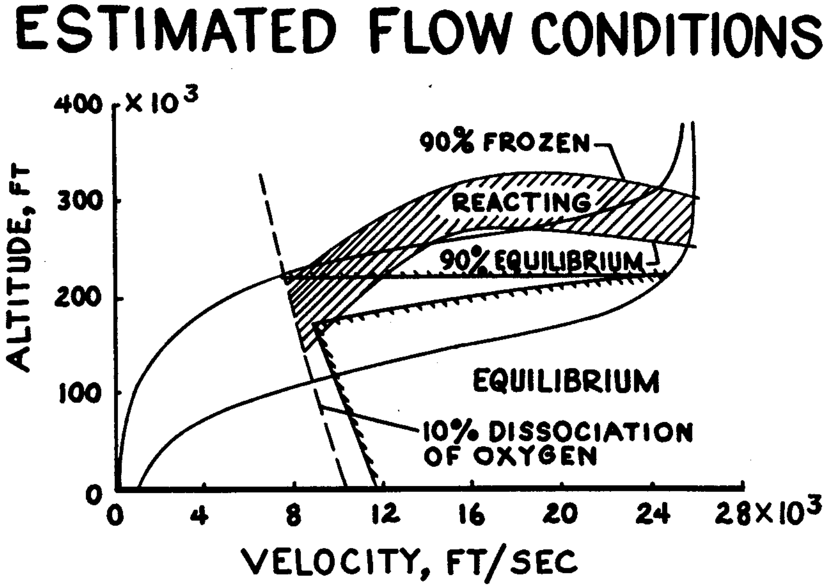
ESTIMATED FLOW CONDITIONS

Figure 2

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