AEDC-TR-66-60

LAUNCHING OF FOAMED PLASTIC MODELS WITH A TWO-STAGE LIGHT-GAS GUN

A. B. Bailey and K. E. Koch

ARO, Inc.

May 1966

Distribution of this document is unlimited.

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

AEDC-TR-66-60

LAUNCHING OF FOAMED PLASTIC MODELS WITH A TWO-STAGE LIGHT-GAS GUN

A. B. Bailey and K. E. Koch
ARO, Inc.

Distribution of this document is unlimited.

AF - AEDC
Arnold AFS Tenn

FOREWORD

The research reported herein was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65402234.

The results of research presented were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The research was conducted from December 9, 1963, to February 1, 1965, under ARO Project No. VK3080, and the manuscript was submitted for publication on February 25, 1966.

The successful development of this ultralightweight model launching technique has been made possible by the support afforded the authors by the Launcher Development Section of the Aerophysics Branch of VKF, AEDC. The analysis of the launcher cycles, with the aid of microwave techniques (developed by the Aerophysics Instrumentation Section) to determine the best cycle for lightweight models, was carried out by A. J. Cable. The modification of commercial molding techniques to suit the present application was carried out by M. D. Prince and B. W. Duke.

Conrad O. Forsythe
Captain, USAF
Aerospace Sciences Division
DCS/Research

Donald R. Eastman, Jr.
DCS/Research

ABSTRACT

Techniques have been developed to launch ultralightweight models (i.e., densities on the order of 1 lb/ft^3) from a two-stage light-gas gun. To date, spheres and cones have been launched with some success. The purpose of the development was to determine whether useful aerodynamic data (e.g., sphere drag) could be obtained in a short aeroballistic range at pressures on the order of 0.01 mm Hg. A number of spheres have been launched in support of this effort, some at pressures as low as 0.03 mm Hg. There is good agreement between these measurements of sphere drag coefficient and those produced in low-density wind tunnels. The application of this technique to a longer range having a lower pressure capability, say, 0.001 mm Hg, would permit measurements to be made in the near-free-molecule flow regime.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

C_D	Drag coefficient
d	Diameter of sphere
M_∞	Free-stream Mach number
m	Model mass
Re_2	Reynolds number based on conditions immediately downstream of a normal shock
S	Sphere cross-sectional area, $\pi d^2/4$
T_W	Model wall temperature
T_∞	Free-stream temperature
t	Time
V	Velocity
ρ	Air density
ρ_m	Model density

SECTION I
INTRODUCTION

The accuracy of drag measurements in an aeroballistic range depends upon the precision with which model weight, diameter, velocity, and deceleration and range temperature and pressure can be measured. Measurement of all of these quantities except deceleration is independent of model material, and in a well instrumented aeroballistic range these quantities can be measured with a high degree of accuracy over a wide range of velocity and pressure. Because deceleration is inversely proportional to the product of model density and the cube of the diameter ($\rho_m d^3$), in order to have a measurable deceleration at low ambient pressures, the practice has been to reduce the model size. Velocity and, hence, deceleration measurements are made by photographing the model position at measured times with respect to a series of fixed points in the range. The problems of detecting and photographing small models limit the applicability of this "small model" technique.

SECTION II
TEST FACILITY

2.1 HYPERVELOCITY PILOT RANGE

The hypervelocity pilot range (Armament Test Cell, Hyperballistic (K)) has a 75-ft instrumented length with six dual-axis shadowgraph stations spaced at 15-ft intervals. Range K was established with the intention of investigating launching and instrumentation techniques for use in other hypervelocity ranges, with particular reference to the 1000-ft hypervelocity range (Armament Test Cell, Hyperballistic (G)) which has an 850-ft instrumented length. Range K consists of the following major components: launcher, blast and range tanks, and instrumentation.

2.2 LAUNCHER

The launcher is a two-stage light-gas gun consisting of a powder chamber, pump tube, high-pressure section, and launch tube. The powder chamber and pump tube are used with a variety of high-pressure sections and launch tubes ranging in internal diameter from 0.5 to 1.0 in. Some idea of the velocity capability of this launcher as a function of in-gun weight is given in Fig. 1.

Two main types of sabots (Fig. 2) are used with this launcher.

1. Aerodynamic - The aerodynamic forces separate the model and the split sabot.
2. Mechanical - The separating forces are provided by mechanical means. The model is initially separated from the sabot by steel pins placed at the muzzle exit and set to interfere with sabot alone. The sabot is then trapped by a piece of lead which has a hole in its center to allow passage of the model, or is deflected onto a catcher plate by an inclined ramp adjusted such that the model can pass freely. Both types of strippers have their particular applications.

2.3 BLAST AND RANGE TANKS

Both of these tanks are 6-ft-diam cylinders connected by a short spool containing a high-vacuum valve which permits the isolation of the two tanks.

The blast tank is 12 ft long and has a series of ports along the sides and upper surface to permit X-ray photography of the model and sabot leaving the muzzle of the gun. At the downrange end of this tank is an easily removable plate with a small hole in its center. This plate serves the purpose of restricting the flow of muzzle gas into the range, preventing entry of sabot fragments generated by stripping, and also of minimizing the effect of muzzle flash on downrange detection equipment.

The range tank is 103 ft long and is equipped with dual-axis shadowgraph stations installed at approximately 15-ft intervals. This system, wholly outside the range tank except for the plastic Fresnel lenses, was designed primarily to photograph the positions and attitude of the model.

The blast and range tanks have independent pumping systems which greatly facilitate testing at low pressures because the range tank can be kept at a low pressure while the gun is cleaned and reloaded. A check on the capability of the range tank pumping system, which consists of a mechanical pump, a Rootes blower and an oil diffusion pump, indicates that pressures on the order of 0.001 mm Hg can be attained relatively easily.

2.4 INSTRUMENTATION

Over the range of pressures considered herein, two pressure gages have been used:

1. Oil micromanometer - This gage is based on one designed for the University of California low-density wind tunnels and used extensively in the VKF low-density and hypersonic wind tunnels (Ref. 1). This instrument has proved to be reliable, repeatable, and to have a resolution on the order of 0.0015 mm Hg.
2. Baratron - This gage is a variable capacitance pressure transducer capable of accurate measurements down to 0.03 mm Hg.

Above 0.5 mm Hg, where the micromanometer still has sufficient resolution to give an accurate measurement, both gages are in good agreement. Below this pressure a new pressure calibrating device, designed and built in VKF, is being used to check the Baratron. These gages and another one used for higher pressure levels are all connected to a stainless steel manifold which can be isolated from the range when not in use and kept at a low pressure. This technique has been helpful in reducing the contamination of the gages by the range environment.

Range tank temperature is measured with copper-constantan thermocouples located at four stations along the length of the range tank.

For the present investigation, a shadow detector has been used to trigger the spark shadowgraph system. This consists of a beam of light shining across the model trajectory onto a phototransistor. The interruption of this light beam by the model causes an electrical pulse to trigger the shadowgraph spark source which, in turn, stops or starts the chronograph connected to that station.

Shadowgrams of the model are obtained for each of the six orthogonal stations. Model position, with respect to the range master axis system, is then determined. These position data, together with the timing values obtained with the 10-mc chronographs, permit the velocity to be calculated to an accuracy generally better than ±0.03 percent.

SECTION III
LIGHTWEIGHT MODELS

Experience with the operation of Range K has indicated that, provided the velocity drop over the instrumented length is at least 1 percent, the sphere drag coefficient can be measured with an accuracy of ±1.5 percent.

The drag coefficient of a body in free flight can be expressed in the form:

$$C_D = m \frac{dV}{dt} \frac{2}{\rho V^2 S} \tag{1}$$

Or, rewriting model mass in terms of model diameter and density,

$$C_D = (4/3)\left[(\rho_m d) \ / \ (\rho V^2)\right](dV/dt) \tag{2}$$

If we consider a 1-percent velocity drop for a 1/2-in.-diam steel sphere having a drag coefficient $C_D = 0.9$, we find from Eq. (2) that such a test can be made at 40 mm Hg. If the product $\rho_m d$ is reduced by several orders of magnitude, then the pressure at which an accuracy of drag measurement of ±1.5 percent is still attainable is reduced correspondingly. In reducing the product $\rho_m d$, detector performance limitation makes it desirable to confine sphere diameter to a minimum of 1/8 in. Now for the steel sphere considered above, $\rho_m d = 240$ in.-lb/ft^3; for a 1/8-in.-diam sphere having a density of 1 lb/ft^3, this product is 1/8. This implies that the pressure at which such a model could be tested is approximately 0.02 mm Hg (assuming $C_D \approx 0.9$). The problem is to achieve these very low model densities.

Hollow metal models were considered, but it was found that models of this form, when they were made light enough to satisfy the above requirement, were not strong enough to survive launching from a light-gas gun. Models of this order of density could be easily made from foamed plastics. However, little data were available on the strength of foamed plastics when exposed to the loads experienced in a light-gas gun.

Therefore, to obtain some idea as to the feasibility of using foamed plastic, a large, 1.8-in.-diam sphere was machined from a slab of foamed plastic (Styrofoam®) having a density of approximately 2.5 lb/ft^3. This particular material is used extensively as insulation in building construction. It is characterized by a small cellular structure which machines well, although the surface finish would be termed aerodynamically rough. A 2.3-in.-cal single-stage gun was used to launch this sphere at a velocity of 4450 ft/sec into a pressure of 0.1 mm Hg. The resulting orthogonal shadowgraph (Fig. 3) pictures indicate no significant model deformation under these conditions of launch. The debris between the model and sabot is considered to have originated in the machining process, where it was occluded in the surface structure, and was shaken loose by the launching pressure pulses. Perhaps the most striking aspect of these pictures is the fact that, although no attempt was made to strip the model from the sabot, the separation between the model and sabot increased with distance downrange even though the weight ratio of sabot to model was on the order of 100:1. (It was found in subsequent tests with these foam models that at low pressures there was a tendency for natural separation to occur.)

Although it was realized that a model with this type of porous surface would not be acceptable aerodynamically, it was decided to pursue the investigation to higher velocities with smaller models. Using the 1-in.-diam launch-tube configuration, it was found that 3/4-in.-diam models of this material could be launched to velocities of 15,000 ft/sec. In this part of the study it was determined that the mode of gun operation was not important for velocities on the order of 8000 ft/sec. However, for velocities greater than this, it was necessary to increase the piston weight from 200 to 1000 gm in order to prevent model distortion caused by the high initial loading characteristic of the lighter piston.

At this stage of development it was decided that foamed plastic models could generate useful aerodynamic data (i.e., drag of a sphere at low pressures). The main problem was to produce a model having an acceptably smooth surface finish. From this point of view the most attractive foamed plastic material appeared to be the one often used in the manufacture of ice chests, packaging for electronic equipment, and children's toys. From the commercial items available, it was evident that a good surface finish could be achieved for small complex shapes. In order to get an idea of its structural suitability, several spheres were machined from a slab of this material having a density of approximately 1 lb/ft^3. The results of these launchings were sufficiently encouraging to warrant further investigation.

A search of the literature and a discussion with a local ice-chest manufacturer revealed that the material is called Dylite® and that it is an expandable polystyrene produced by Koppers Company, Inc. Forming shapes from this material is a two-stage process. The original material is a clear plastic bead having a diameter which varies between 1/32 and 1/8 in. The first stage in the process is to place the beads in a steam chest where they expand and become white and opaque. (A section through one of these spheres, which has a smooth surface, reveals that the internal structure is composed of a very large number of minute, uniform cells.) These pre-expanded beads, three to five times their original size, are loaded into a mold, and steam is passed through the mold. After a certain length of time, determined from experience, the steam flow is stopped, the mold is opened, and the shape is removed.

In applying this technique to the manufacture of high-quality spheres composed of single beads and multiple beads, some modifications to the above commercial method have to be made. In the first expansion of the beads, the fact that in a commercial process some of them are of poor quality makes little difference to the structural integrity of an item that contains thousands. For the present application, it was found that by carefully selecting the best of the pre-expanded beads, the number of failures in the second stage of molding was greatly reduced. For the very small scale of the effort, as opposed to a commercial undertaking, the beads were first expanded by placing them on a light aluminum tray which was floated on some boiling water. Because of the small scale of the models, steam could not be passed through the molds. This problem was solved by making the molds (Fig. 4) out of several well-fitting pieces and depending upon the natural leakage of steam into the interior of the mold to effect the expansion of the beads contained therein. The required density of the model determines the number of pre-expanded beads placed in the mold. The mold is then placed in the container, shown at the top of the figure, which serves as a clamp for the mold. Experience has shown that the quality of the final model is much improved by carrying out this part of the process at a pressure on the order of 30 psia. For this purpose, a commercially available pressure cooker is used. Photographs of some of the models and sabots are shown in Figs. 5 and 6.

The lowest density attained with this method was very nearly 1 lb/ft^3. This was obtained by expanding a single bead to 1/4-in. diameter. Many attempts were made to expand a single bead to 7/16-in. diameter which, had it been suceessful, would have given a density of less than 1 lb/ft^3. However, the benefit of producing such a model was not great enough to warrant the large number of attempts that it soon became evident would be necessary. All models having a diameter greater than 1/4 in. were made from more than one bead and had densities ranging up to 5 lb/ft^3. A different technique was used to produce the 1/8-in.-diam spheres. By carefully screening the pre-expanded spheres, a number of usable 1/8-in.-diam spheres having a random density variation was found.

Several of the multiple bead models were sectioned and studied under a microscope. This revealed that the bonding between the individual beads was good and that the individual beads were uniform in themselves. A check of the models in a vacuum chamber indicated that there was no deformation as the pressure was reduced.

The mass changes caused by outgassing were investigated as follows: A slab of Dylite approximately 1.5 by 6.0 by 18 in. was weighed and then placed in a vacuum chamber. Seventeen hours later it was removed and reweighed. A weight loss of 2.5 percent (±10 percent) was noted immediately after removal from the vacuum chamber. Further measurements were made which indicated a regaining of weight with time. This test cannot be considered conclusive since the slab of Dylite collapsed to about 50 percent of its original volume on being exposed to the vacuum. The reason for this may be attributable to the fact that the specimen was cut from a larger slab and consequently the outer surfaces consisted of many partial beads. Since the models did not collapse under static testing or during launch, and their surfaces consisted of whole beads, the weight loss from a model presumably would be less than that of the slab, i.e., less than 2.5 percent.

To study this problem further, a sphere of the type tested in the range was immersed in a small flask of well-outgassed diffusion pump oil. The flask, oil, and model were then weighed. Then they were placed in a bell jar and held at a pressure of 0.02 mm Hg for 30 min (a time comparable to the exposure in the range). Bubbles were seen to emanate from the sphere in this time, indicating the possibility of surface porosity even with a sealed bead. On removal from the bell jar the flask, oil, and sphere were reweighed and found to have a weight loss of 2.5 percent (±10 percent). Furthermore, no distortion of the sphere occurred.

Although the changes in weight indicated by the two experiments just described are not great enough to cause inadmissible errors in the experimental determination of drag, there is an additional argument that may be advanced. Namely, noting that the spheres were weighed in air and that outgassing would remove mainly air, then it may be concluded that the air removed by outgassing was not included in the weight determined by the balance originally. Thus, no change in weight arose from outgassing of air alone.

With the problem of manufacturing the models solved, the next step was to devise a successful method of making a clean launch. After several attempts with a pin and lead orifice stripper (Fig. 2), it became apparent that the models were being destroyed by the debris generated when the sabot struck the lead block. The pin and ramp stripper shown in Fig. 2 has proved to be a successful method for launching these models. Orthogonal photographs (Fig. 7) of a variety of models in free flight in the range show that if there is any model distortion it is not evident in photographs of this type.

The results of some sphere drag measurements are shown in Figs. 8 and 9. The lowest pressure at which drag measurements have been made is approximately 0.03 mm Hg. Lower pressures are within the capability of the present system; the indications of the results obtained to date are that testing at pressures of 0.01 mm Hg should produce meaningful results. At such a pressure, the mean free path in the range air is on the order of 0.2 in., which corresponds to a Knudsen number of 3 for a 1/8-in.-diam model. A comparison of the present results with those obtained in low-density wind tunnels (Refs. 2 through 9) indicates a good measure of agreement.

Some limited work has been done on launching blunt cones, facing both forward and rearward (Fig. 10). Because these launches were only to study model structural behavior, sabots were not stripped. The success of these launchings seems to indicate that the measurement of drag of other ultralightweight shapes, in addition to spheres, is within the capability of the present system.

SECTION IV
CONCLUSIONS

The usefulness of a short, variable pressure aeroballistic range for the measurement of sphere drag has been shown to be considerably increased by the use of ultralightweight models. In fact, it has been shown that, at a fixed velocity, useful data can be obtained over the pressure range from 0.03 to 760 mm Hg. The indications are that if this technique were used in longer ranges, usable data could be achieved at pressures as low as 0.001 mm Hg. Such a technique would be useful in that high velocity data could then be produced in the near-free-molecule flow regime with the flow properties known with great accuracy and with no support interference.

REFERENCES

1. Bailey, A. B. and Boylan, D. E. "Some Experiments on Impact-Pressure Probes in a Low-Density Hypervelocity Flow." AEDC-TN-61-161 (AD 268391), December 1961.
2. Kinslow, Max and Potter, J. L. "The Drag of Spheres in Rarefied Hypervelocity Flow." AEDC-TDR-62-205 (AD 290519), December 1962.
3. Slattery, J. C., Friichtenicht, J. F. and Hamermesh, B. "Interaction of Micrometeorites with Gaseous Targets." AIAA Journal, Vol. 2, No. 3, March 1964, pp. 543-548.
4. Geiger, R. E. "Some Sphere Drag Measurements in Low-Density Shock Tunnel Flows." G. E. R6 3SD23, July 1963.
5. May, Albert. "Supersonic Drag of Spheres at Low Reynolds Numbers in Free Flight." Navord R 4392, December 1956.
6. May, A. and Witt, A. "Free Flight Determinations of the Drag Coefficients of Spheres." Journal of the Aeronautical Sciences, Vol. 20, No. 9, September 1963, pp. 635-638.
7. Hodges, A. J. "The Drag Coefficient of Very High Velocity Spheres." Journal of the Aeronautical Sciences, Vol. 24, No. 10, October 1957, pp. 755-758.
8. Charters, A. and Thomas, R. "The Aerodynamic Performance of Small Spheres from Subsonic to High Supersonic Velocities." Journal of the Aeronautical Sciences, Vol. 12, No. 4, October 1945, pp. 468-476.
9. Aroesty, Jerome. "Sphere Drag in Low Density Supersonic Flow." University of California Report No. HE-150-192, January 1962.
10. Davis, R. T. and Flugge-Lotz, I. "Second-Order Boundary-Layer Effects in Hypersonic Flow Past Axisymmetric Blunt Bodies." Journal Fluid Mechanics, Vol. 20, Part 4, 1964, pp. 593-623.

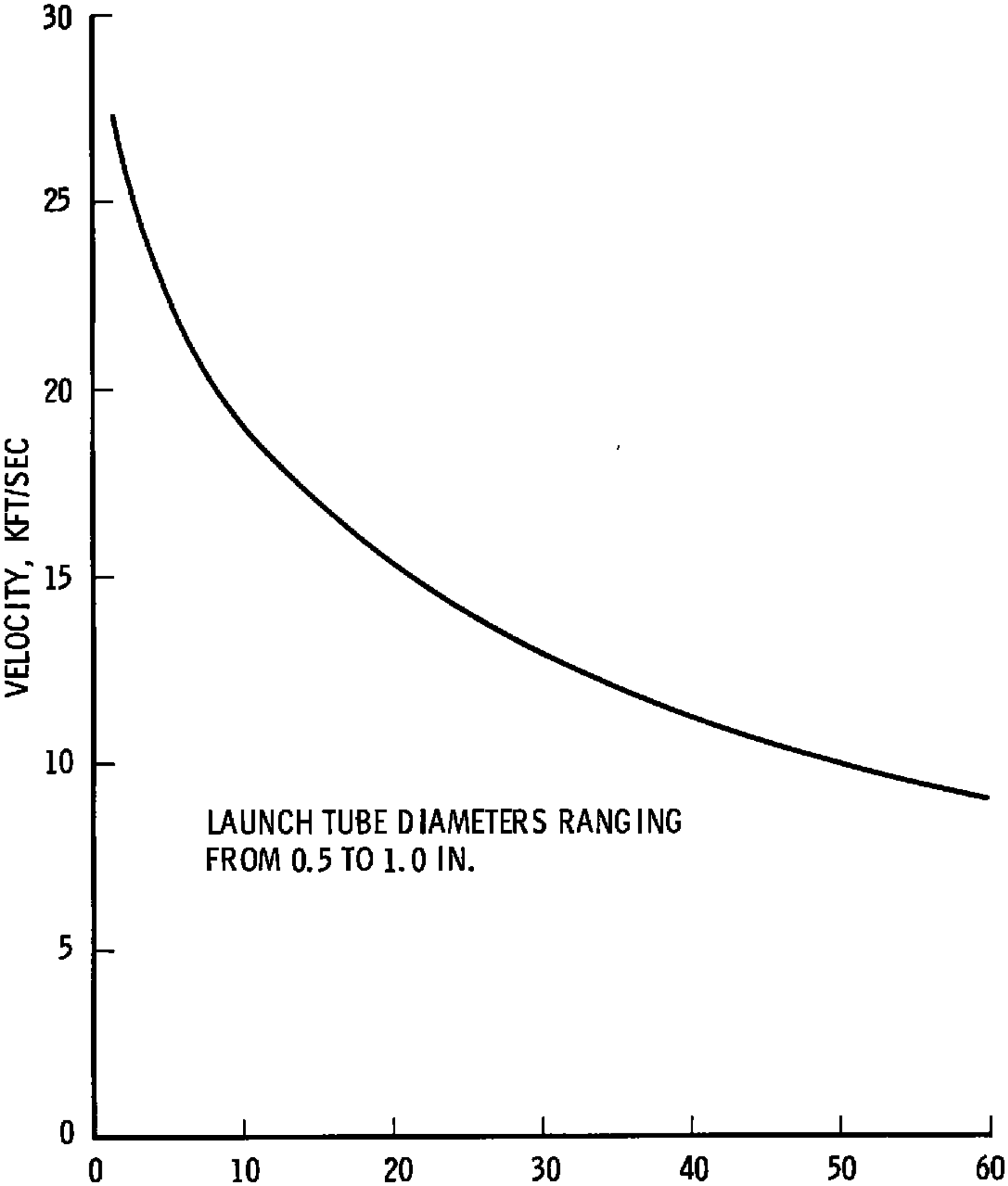
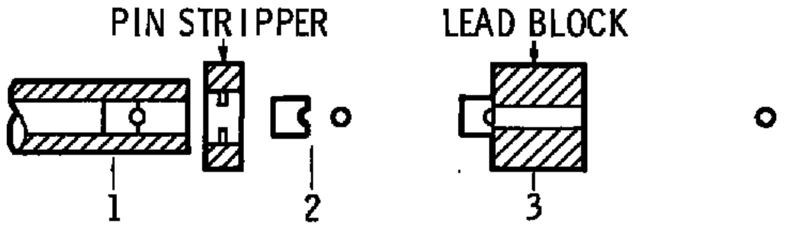
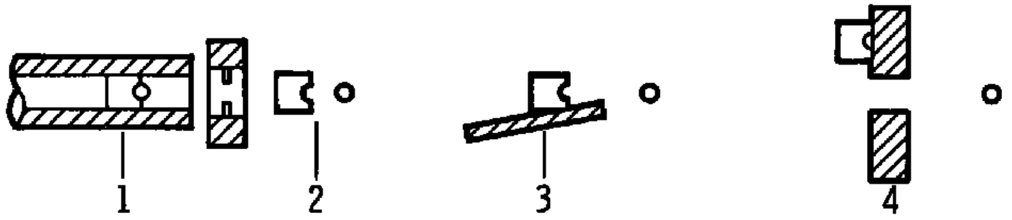


Fig. 1 Operational Capability of the Range K Two-Stage Light-Gas Gun



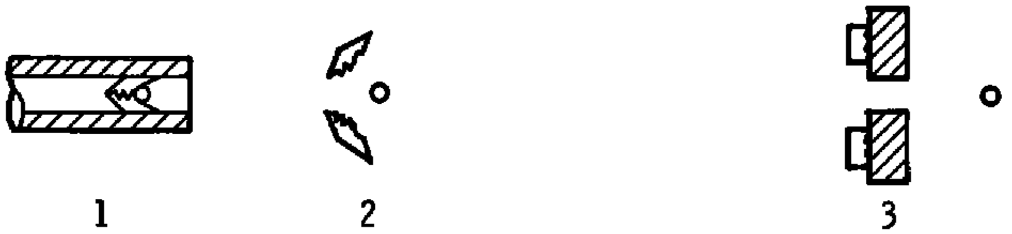
1. MODEL AND SABOT TOGETHER IN LAUNCH TUBE.
2. MODEL AND SABOT SEPARATED AFTER PASSING THROUGH PIN STRIPPER.
3. SABOT ARRESTED BY LEAD BLOCK - MODEL PASSES THROUGH A HOLE IN THE BLOCK AND ON DOWN RANGE.

PIN AND LEAD ORIFICE STRIPPER



1.-2. AS ABOVE.
3. SABOT STRIKES ANGLED RAMP AND DEFLECTS VERTICALLY.
4. SABOT STRIKES CATCHER PLATE - SPHERE PASSES THROUGH HOLE AND ON DOWN RANGE.

PIN AND RAMP STRIPPER



1. MODEL AND SABOT TOGETHER IN LAUNCH TUBE.
2. PETALLED SABOT SPREADING UNDER ACTION OF AERODYNAMIC FORCES.
3. SABOT ARRESTED BY CATCHER PLATE - SPHERE PASSES THROUGH HOLE AND ON DOWN RANGE.

AERODYNAMIC STRIPPER

Fig. 2 Model Separation Techniques Used in Range K

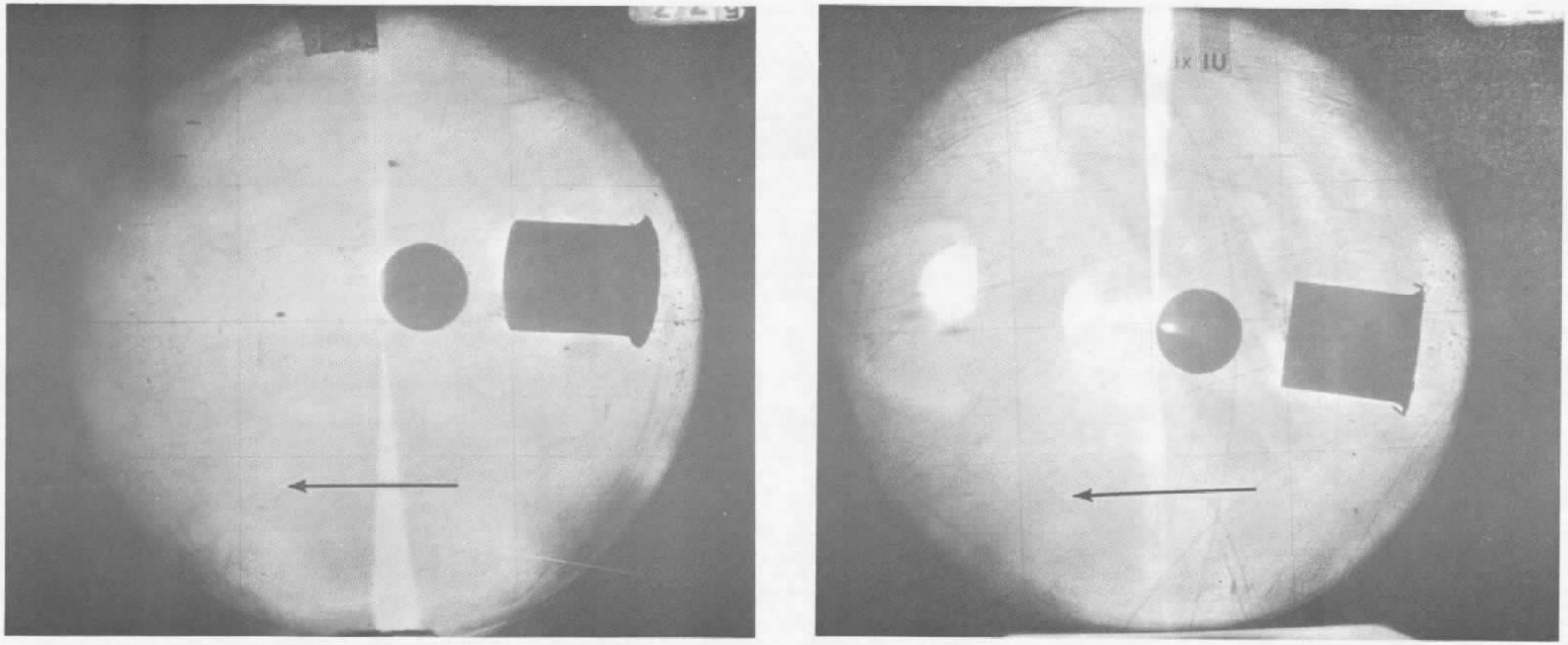


Fig. 3 Orthogonal In-Flight Photographs of a 1.8-in.-diam Foamed Plastic Sphere

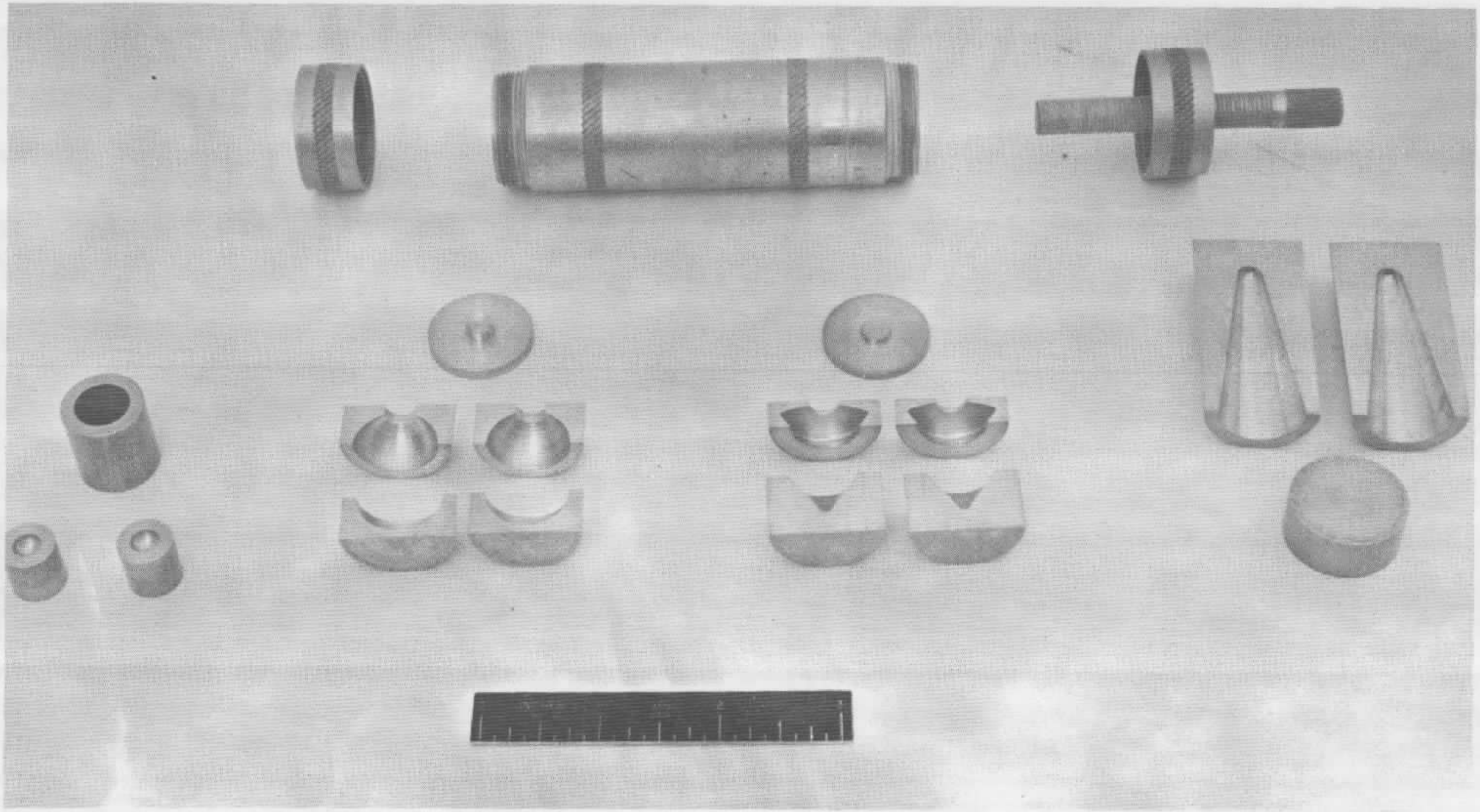


Fig. 4 Molds Used in the Fabrication of Dylite Models

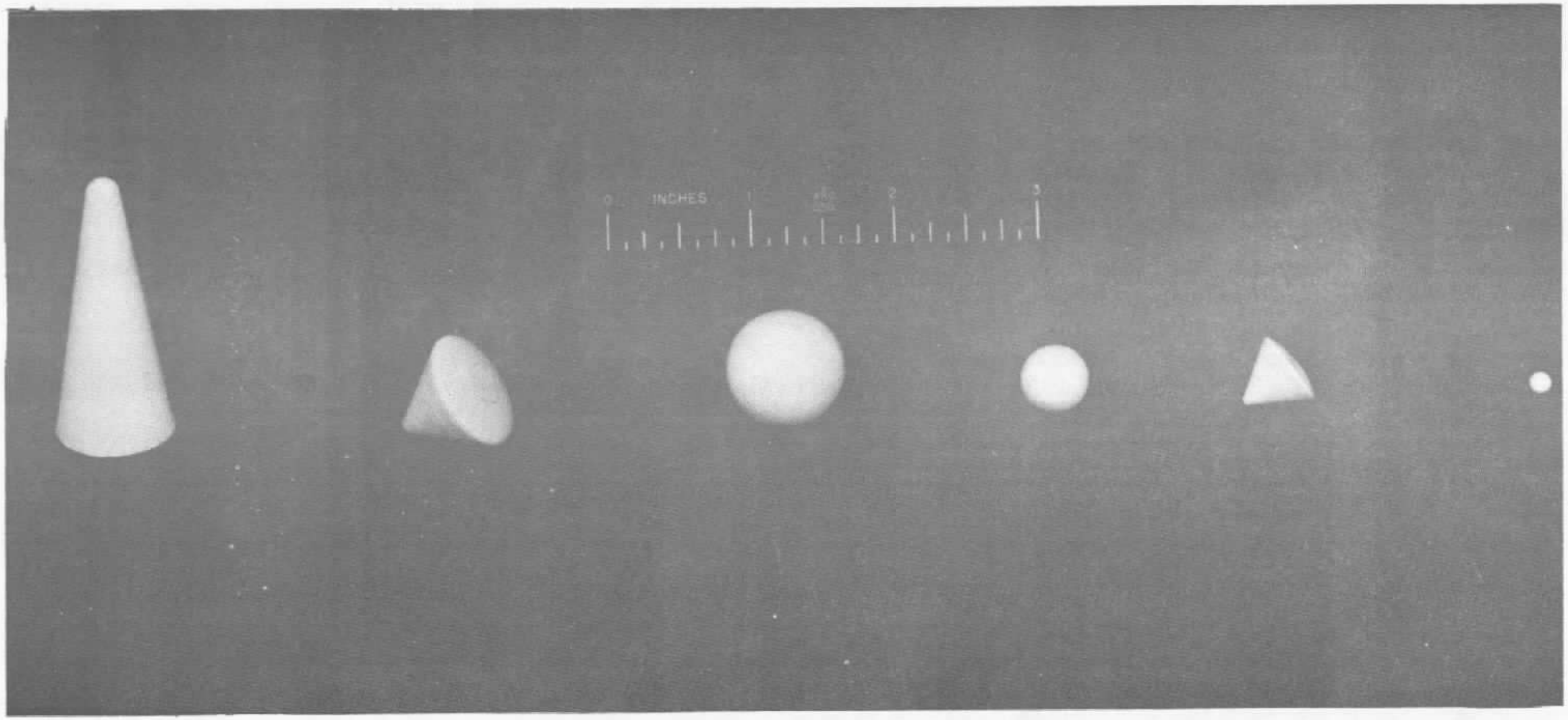


Fig. 5 Models Formed from Dylite

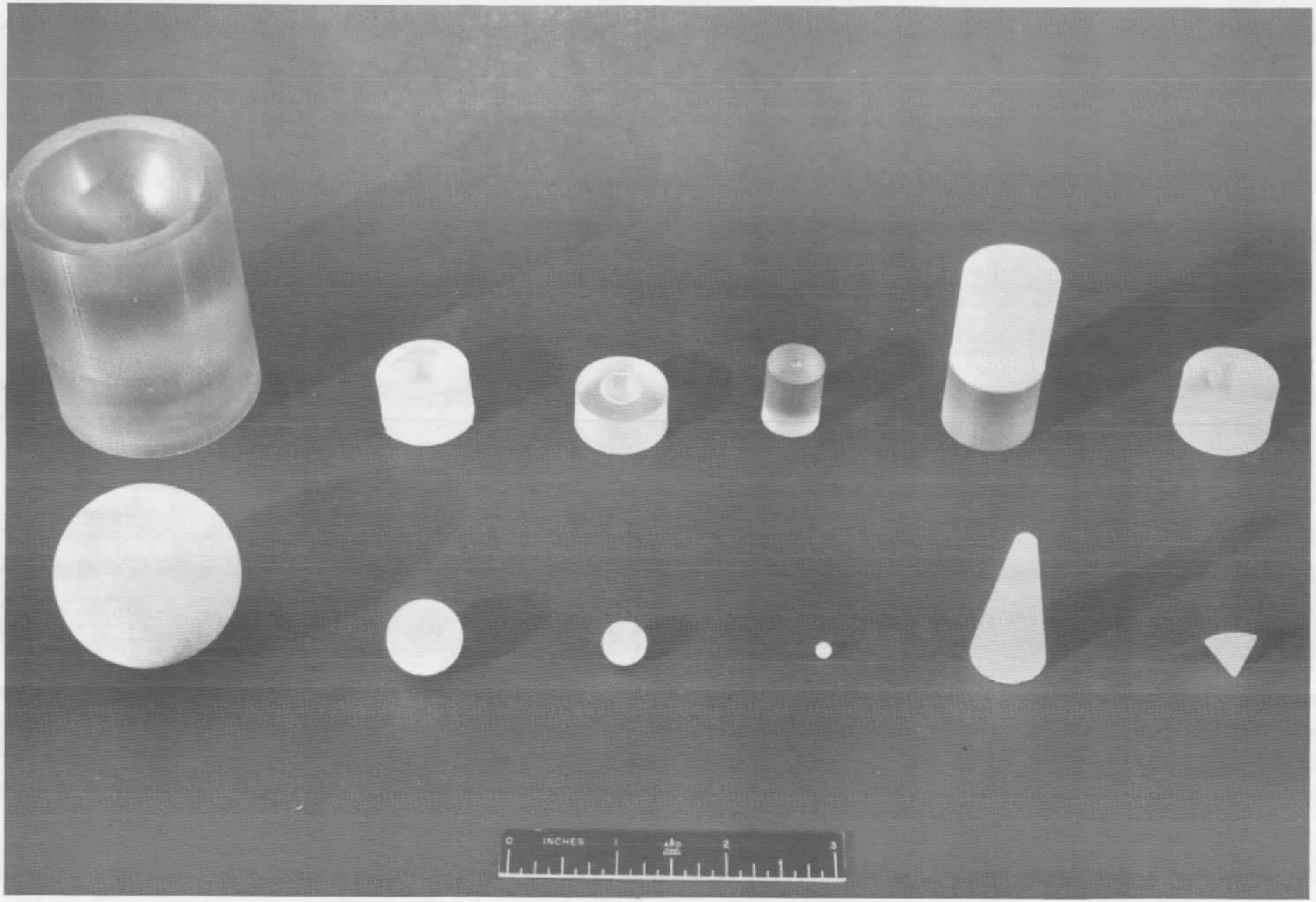
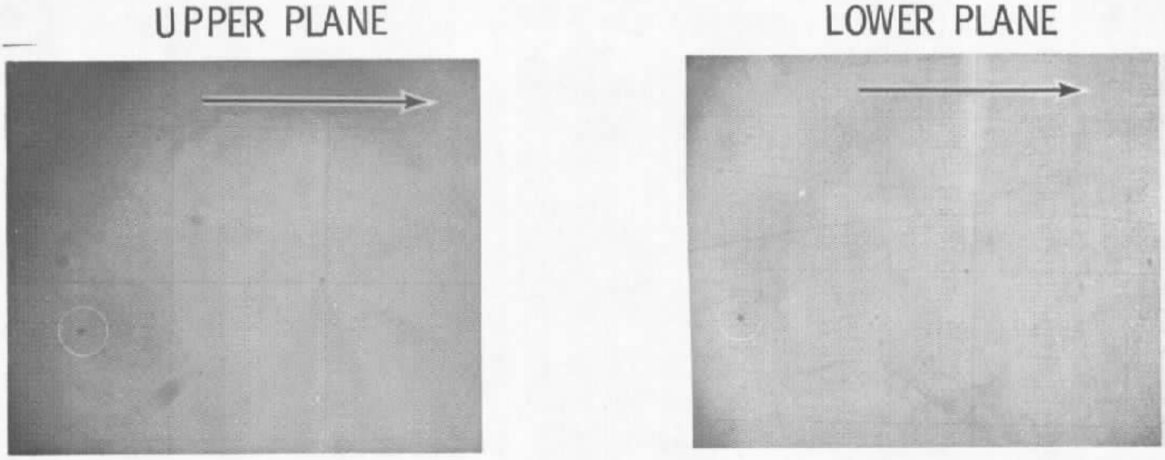
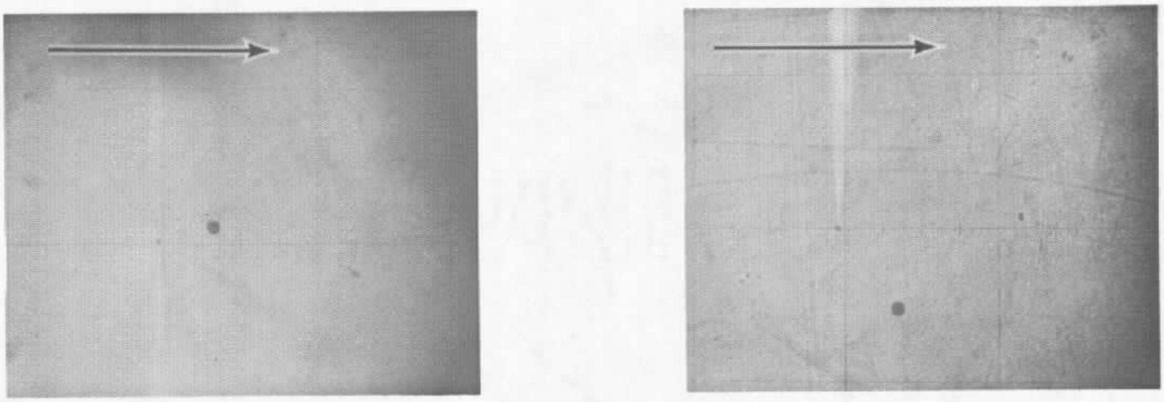


Fig. 6 Dylite Models and Their Sabots



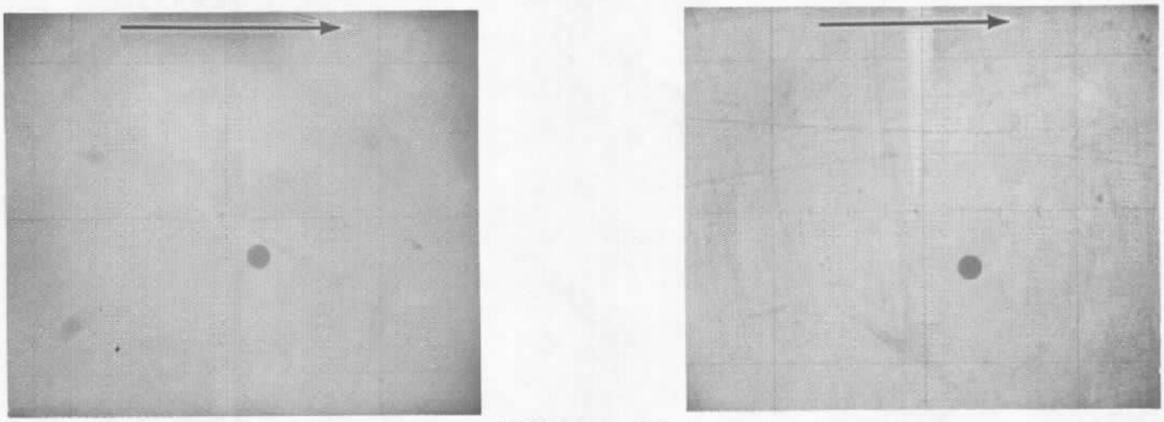
SHOT 1169

DIAMETER = 1/8-IN., VELOCITY = 10,700 FT/SEC, PRESSURE = 0.036 MMHG



SHOT 1147

DIAMETER = 1/4-IN., VELOCITY = 10,100 FT/SEC, PRESSURE = 0.049 MMHG



SHOT 1134

DIAMETER = 7/16-IN., VELOCITY = 10,250 FT/SEC, PRESSURE = 0.158 MMHG

Fig. 7 Dylite Spheres in Free Flight

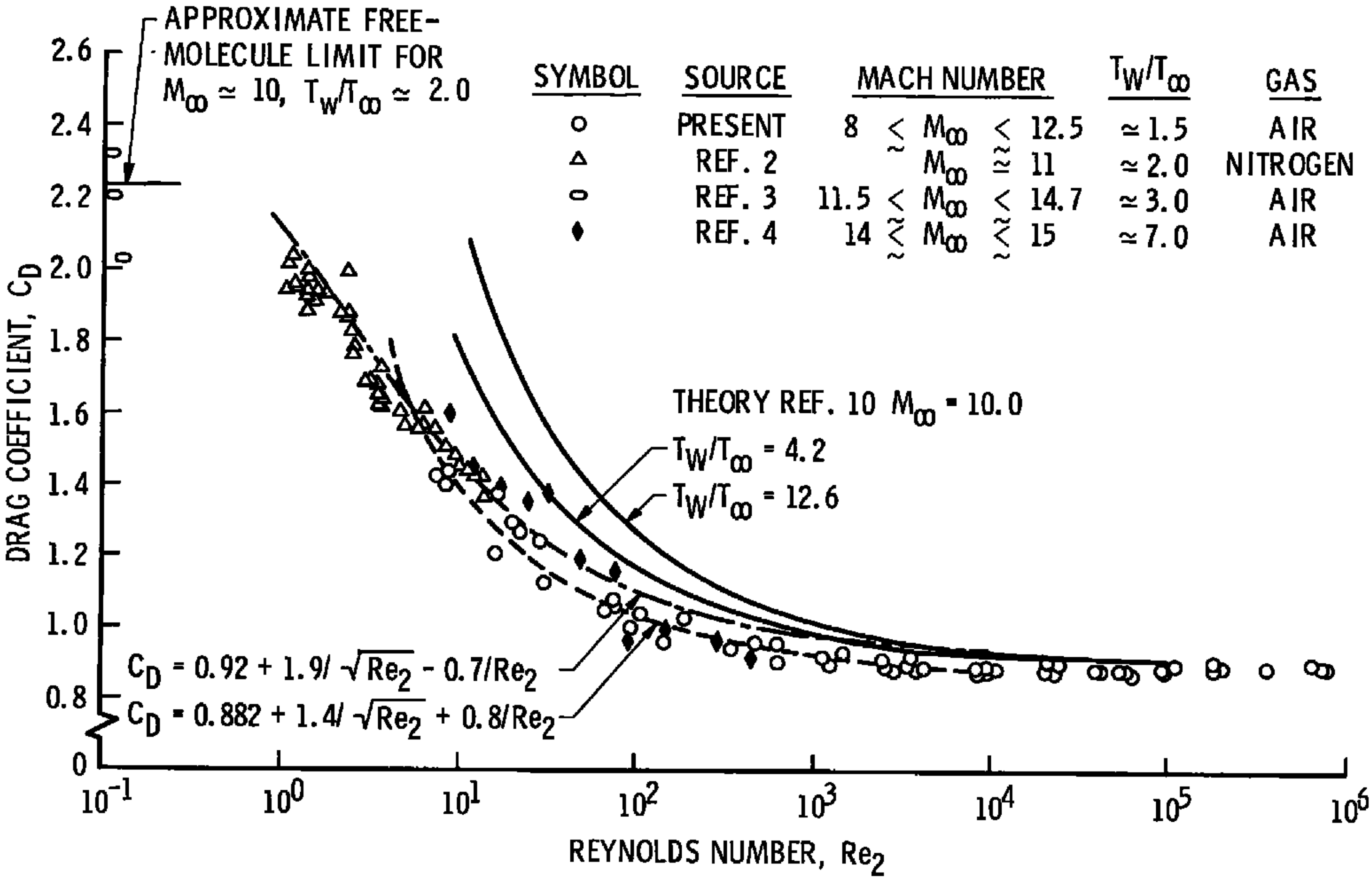


Fig. 8 Variation of Support-Free Sphere Drag Coefficient with Reynolds Number ($8 \leq M_\infty \leq 15$)

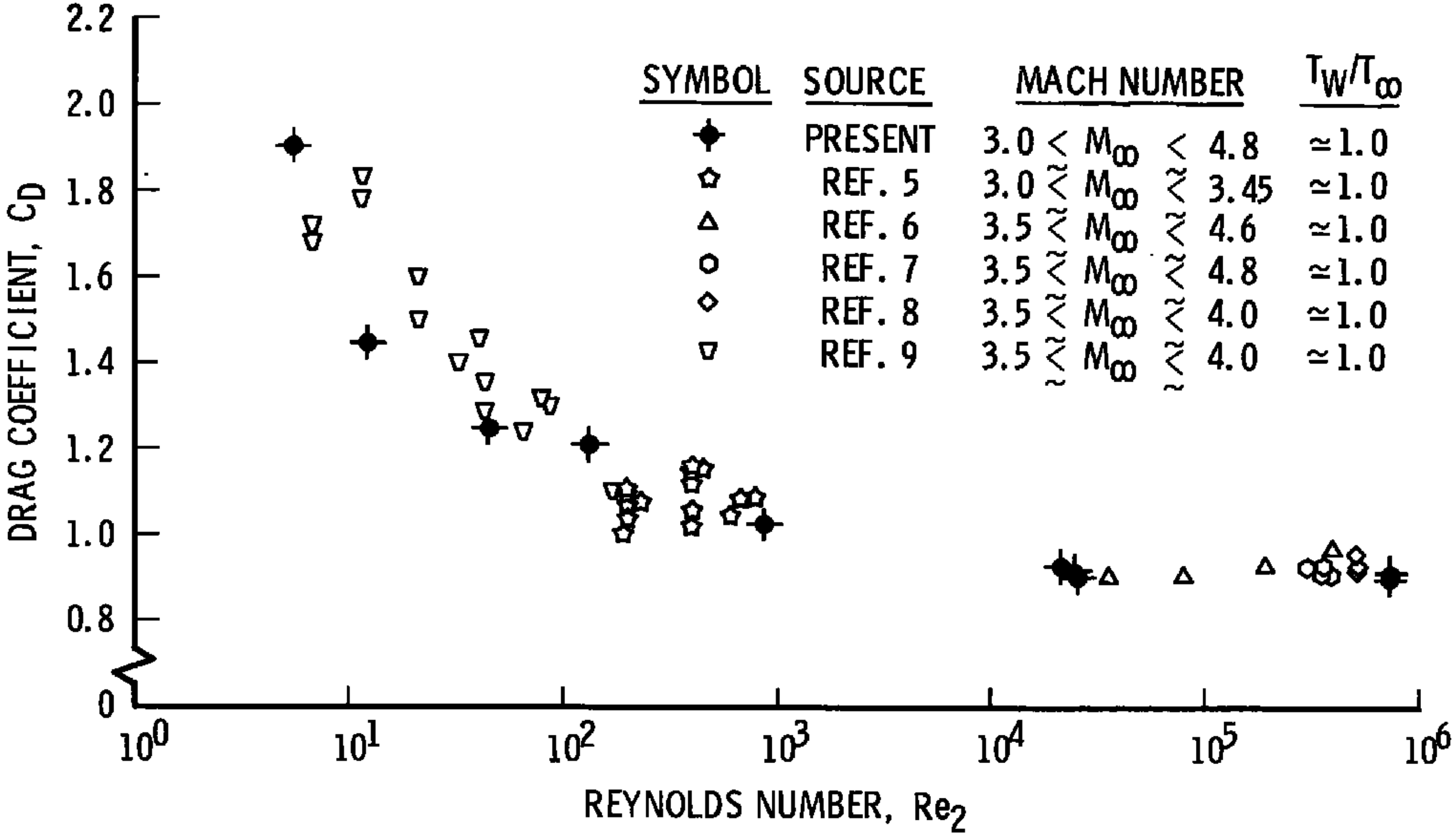
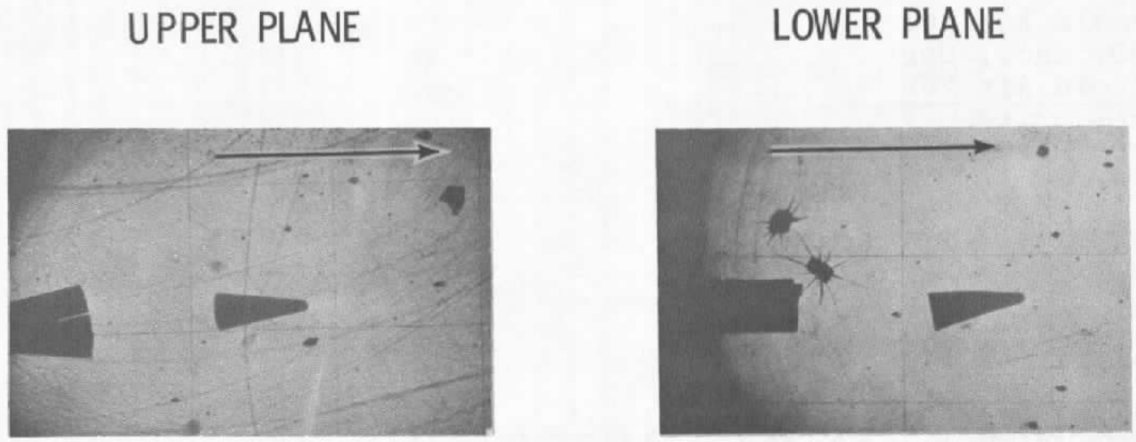
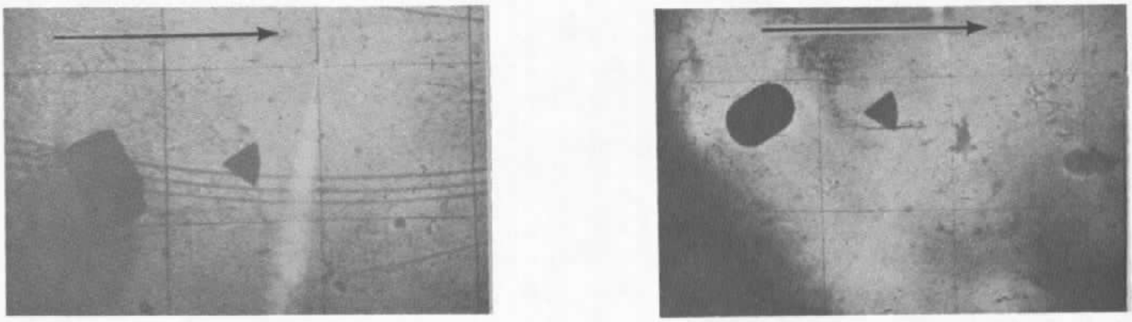


Fig. 9 Variation of Support-Free Sphere Drag Coefficient with Reynolds Number ($3 \leq M_\infty \leq 5$)



SHOT 730

MODEL = 9-DEG SEMI-ANGLE BLUNT CONE,
VELOCITY = 5500 FT/SEC,
PRESSURE = 0.069 MMHG



SHOT 765

MODEL = APOLLO TYPE,
VELOCITY = 5700 FT/SEC,
PRESSURE = 0.222 MMHG

Fig. 10 Dylite Cones in Free Flight

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Arnold Engineering Development Center (AEDC)
ARO, Inc., Operating Contractor
Arnold Air Force Station, Tennessee

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE
LAUNCHING OF FOAMED PLASTIC MODELS WITH A TWO-STAGE LIGHT-GAS GUN

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
N/A

5. AUTHOR(S) *(Last name, first name, initial)*
Bailey, A. B. and Koch, K. E., ARO, Inc.

6. REPORT DATE May 1966	**7a. TOTAL NO. OF PAGES** 26	**7b. NO. OF REFS** 10

8a. CONTRACT OR GRANT NO.
AF 40(600)-1200

b. xxxxxxxxx
Program Element 65402234

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AEDC-TR-66-60

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
N/A

10. AVAILABILITY/LIMITATION NOTICES
Qualified users may obtain copies of this report from DDC.

11. SUPPLEMENTARY NOTES
N/A

12. SPONSORING MILITARY ACTIVITY
Arnold Engineering Development Center
(AEDC), Air Force Systems Command
(AFSC), Arnold AF Station, Tenn.

13. ABSTRACT
Techniques have been developed to launch ultralightweight models (i.e., densities on the order of 1 lb/ft^3) from a two-stage light-gas gun. To date, spheres and cones have been launched with some success. The purpose of the development was to determine whether useful aerodynamic data (e.g., sphere drag) could be obtained in a short aeroballistic range at pressures on the order of 0.01 mm Hg. A number of spheres have been launched in support of this effort, some at pressures as low as 0.03 mm Hg. There is good agreement between these measurements of sphere drag coefficient and those produced in low-density wind tunnels. The application of this technique to a longer range having a lower pressure capability, say, 0.001 mm Hg , would permit measurements to be made in the near-free-molecule flow regime.

DD FORM 1 JAN 64 1473

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
spheres						
cones						
drag						
foamed plastic models						
light gas gun						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.