APL/JHU FREE FLIGHT TESTS OF THE
GENERAL PURPOSE HEAT SOURCE MODULE

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AFWAL/FIMM

TESTING: 5 - 7 MARCH 1984

TEST SUMMARY DOCUMENT

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NOMENCLATURE

$I_{xx}, I_{yy},$	moments of inertia about the X, Y, and Z - axis,
I_{zz}	respectively
P_{atm}	atmospheric pressure
q	dynamic pressure, reference: rake system probe
q_t	dynamic pressure, reference: tunnel pitot-static tube
R	radius location
$R\phi$	tunnel radius, 6 foot
$S.G.$	specific gravity
$Temp$	temperature in test section
V_{avg}	average velocity, reference: rake system
V_{ind}	indicated velocity, reference: velocity meter
V_t	tunnel velocity, reference: tunnel pitot-static tube
ρ	density of air

1.0 INTRODUCTION

The work reported herein was conducted by the Aeromechanics Division of the Flight Dynamics Laboratory (AFWAL/FIM) located at Wright-Patterson Air Force Base (W-PAFB), Ohio. The test was sponsored by the U. S. Department of Energy, Office of Space Nuclear Projects, Washington D. C. for Johns Hopkins University, Applied Physics Laboratory (APL), Laurel, Maryland, under Job Order Number DOE08401. AFWAL/FIM was reimbursed by DOE for this test.

Project engineers were E. F. Lucero and J. C. Hagan from APL (a Navy contractor providing work for DOE under a DOE/Navy agreement). The test was conducted in the 12 foot Vertical Wind Tunnel (VWT) under the direction of the Experimental Aerodynamics Group and the support of the Experimental Engineering Branch.

The purpose of the test was to obtain statistical information on the dynamics of the General Purpose Heat Source (GPHS) module at terminal speeds. Models were designed to aerodynamically and dynamically represent the GPHS module. Normal and high speed photographic coverage documented the motion of the models. For a general description and purpose of the GPHS modules, refer to references 1 and 2.

This report documents test parameters and techniques for the free-spin tests. It does not include data analysis, which is beyond the scope of this report.

2.0 APPARATUS

2.1 TEST FACILITY

The Air Force Flight Dynamics Laboratory 12 foot Vertical Wind Tunnel is an atmospheric pressure, annular return, closed circuit wind tunnel with an open throat twelve feet in diameter. The airflow is directed vertically upward through the test section. The velocity range of the tunnel is from 0 to 150 ft/sec.

A 1000 horsepower variable - speed DC motor drives the four-bladed fan at speeds between 0 and 875 RPM. A general diagram of the tunnel is shown in Figures 1 and 2. See Table 1 for additional information about the tunnel and its capabilities.

2.2 TEST ARTICLE

The 4950th Test Wing Zone Shop (WPAFB, Ohio) fabricated two sets of GPHS module models and duplicates. One set of models simulates the moments of inertia of the GPHS module, but have different weights and scales. The second set are full scale models, but have different weights and moments of inertia. The GPHS module is described in Figure 3.

Required model weights were calculated based on the wind tunnels maximum speed of 137 ft/sec (with a safety net present). Although this is slightly lower than the terminal velocity of the GPHS module (165 ft/sec), the aerodynamic coefficients should remain constant. For further information on the procedures used to arrive at the desired model designs, refer to Reference 3.

To meet design specifications, the models were homogeneous. Epoxy casting compounds were selected for the model material because of their range in specific gravities and their ease in being casted homogeneously. Three materials from REN Plastics were chosen because of their availability, machinability, and casting properties.

A total of 10 models were fabricated, 6 having constant scale (Models 1-6) and 4 having constant moments of inertia (Models 7-10). A summary of the model parameters is given in Table 2. Refer to Figure 3 for dimensions of the full scale model. The set of models simulating the moments of inertia of the GPHS module, but having different scales, are shown in Figure 4. Figures 5 and 6 are photographs of the two sets of models along with their duplicates.

The models were first casted and then machined to the required dimensions. After casting, the models did contain some small voids; however, the models did appear to be homogeneous in nature. The hardener to resin ratio for the RP-1710 material was varied to improve its casting properties; however, this caused the specific gravity to vary slightly.

2.3 INSTRUMENTATION

Photographic coverage of the free-flight motion of the GPHS models was recorded on film with a high speed camera. Most test sequences were shot at a normal 24 frames/second. However, on some test sequences, when the models were more dynamic, their motion was recorded at 100 frames/second. A video system was also used to record the motion of the models and provide a quick playback capability.

Test parameters for this experiment included velocity, temperature, and atmospheric pressure. Velocity was measured by a velocity meter located 3 feet below the test section lip and 3.75 inches from the tunnel wall. A digital light display of the velocity reading was located in the test section. Prior to a test sequence the velocity reading was recorded on film. Another digital display in the test section was used to identify the model being tested and the launch method. This was also recorded on film. Temperature was measured using a standard thermocouple and atmospheric pressure was measured using a mercury column.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

The majority of the test runs were conducted with both horizontal and vertical safety nets installed in the test section. The safety nets protected personnel and equipment from being struck by the model. The nets also protected the models from being severely damaged since they were susceptible to fracturing. Care was taken with the models to obtain the greatest number of test runs before the models became unusable. A duplicate was made in case a total failure occurred.

The vertical safety net has a 1 inch mesh and the horizontal safety net has a 3/4 inch mesh of 3/32 inch diameter nylon. The vertical net stretches from the tunnel lip to the diffuser mouth. Three slits are present in the vertical net to act as windows. Velcro strips are used to fasten them securely to the net. This net was present for the entire test. The horizontal safety net attaches to the tunnel lip and is then tied down to the tunnel at various locations. The final effect of being tied down is that a 3 foot diameter section of the net, at the tunnel center-line, is 2 feet below the tunnel lip.

A limited number of test runs were conducted without the horizontal safety net. This allowed for a greater maximum velocity (150 ft/sec) and better quality flow. However, without the horizontal net present it was difficult to retrieve the model quickly since it would come to rest at the honeycomb section.

The test was conducted at velocities ranging from 105 to 140 ft/sec. Test conditions are summarized along with the test sequence in Table 3.

3.1.1 TEST SEQUENCE

Testing was conducted between 5 and 7 March 1984. The first day of testing was devoted to preliminary work and data was taken the following two days. Symbols were painted on the models to distinguish their flight orientation. A description of the symbol system used is given in Figure 7 and Table 4.

Since the models made from RP-1710 varied in specific gravity, duplicates (Models 2, 8) were considered as independent test models. Therefore, models 1, 2, 3, 5, 7, 8 and 9 were tested.

The tunnel was first brought up to speed, and then the models were hand-launched into the airstream from a window in the vertical net. Because of the dynamics of the model in free-flight, it was necessary to adjust the tunnel velocity during a test run to keep the model floating. The models were subjected to several different initial conditions for the test, always hand-launched. A summary of the actual test activities is found in Table 3.

3.2 DATA CORRECTIONS

3.2.1 TEST SECTION FLOW

A dynamic pressure calibration was completed prior to the GPHS test using a 24 pitot-static probe rake system. Data was collected at several locations, with and without the horizontal safety net. The calibration set-up and test locations are shown in Figures 8 and 9. Figures 10 through 21 are plots of the dynamic pressure ratio versus tunnel span. The tunnel dynamic pressure was referenced to another pitot-static tube located 3 foot below the tunnel lip and 3.75 inches from the tunnel wall.

The velocity meter was calibrated to the tunnel pitot-static tube after the test. An average tunnel velocity was determined by averaging the data from the probes at a certain height (1 in. or 45 in.) and assuming a 10 foot diameter useable tunnel testing area. These plots are shown in Figure 22.

The VWT has a comparatively high level of turbulence intensity, especially with the horizontal safety net installed. A turbulence survey was conducted in 1979 using a hot-wire anemometer. Turbulence intensities were measured 7 feet above the tunnel lip and are shown in Figures 23 and 24.

3.3 UNCERTAINTY OF MEASUREMENT

3.3.1 TEST ARTICLES

Although the test models did contain some small voids, they appeared homogeneous in nature. A tolerance of ± 0.002 inches was kept on the major dimensions of the GPHS models and the tolerance for the chamfers was ± 0.004 inches. The edges of the test models were rounded with a hand file to a very small radius. The models were weighed to within ± 0.0005 pounds.

3.3.2 TEST SECTION FLOW

The airflow quality with the horizontal safety net present is much less than that when the tunnel is empty. Therefore, identical test runs were repeated without the horizontal safety net to visually determine if the change in air flow quality would change the free-flight motion characteristics of the GPHS model.

Turbulence can cause the flow pattern in a tunnel to be similar to the flow pattern in free air at a higher Reynolds number. However, the aerodynamic coefficients of the GPHS module should remain constant around the same Reynolds number. For a further discussion on this subject, refer to Reference 4.

4.0 DATA PACKAGE PRESENTATION

The data package contained (1) 16mm high speed film, (2) video tape recordings, and (3) test article photographs. The entire package was delivered to Messrs E. F. Lucero and J. C. Hagan, Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland. Requests for these data should be submitted to Messrs Lucero and Hagan. The originals are on file at the Vertical Wind Tunnel.

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3. APL/JHU Letter ANSP-241, "Design of Models for Wind Tunnel Simulation of GPHS Module Motion at Terminal Speeds". E. F. Lucero to J. C. Hagan.
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FIGURE 1.

VERTICAL WIND TUNNEL

1 / 120 SCALE

Figure 2. Vertical Wind Tunnel
3-D View

Dimensions in inches

Weight = 3.19 lbs

$I_{xx} = 12.48 \times 10^{-4}$ ft - lb_f-sec²
 $I_{yy} = 8.01 \times 10^{-4}$ ft - lb_f-sec²
 $I_{zz} = 8.52 \times 10^{-4}$ ft - lb_f-sec²

figure 3. GPHS module (scale = 1.0)
(models 1-6)

DIMENSIONS IN INCHES

FIGURE 4. GPHS MODULE (MOMENTS OF INERTIA = CONSTANT)

Figure 5. GPHS Models 1-6
Scale = 1.0

Figure 6. GPHS Models 7-10
Moments of Inertia = constant

VWT
PROJECT
NUMBER
DOE08401
GPHS FREE
FLIGHT TEST
DAYS 5→7 MAR84

Figure 7. Model Orientation Designation
Models 1-6

FIGURE 8.

VERTICAL WIND TUNNEL FLOW FIELD SURVEY RAKE AND PROBE POSITIONS

FIGURE 9.

VERTICAL WIND TUNNEL FLOW FIELD SURVEY RAKE AND PROBE POSITIONS

DATA LOCATIONS USED FOR THE DYNAMIC PRESSURE CALIBRATION

FIGURE 10.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Horizontal Net
 1 in. above lip
 -27.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2058$ psf
 Temp = 525 R

46 1323

10 X 10 TO 1 INCH 7 X 10 INCHES
 KEUFEL & E SER CO MADE IN USA

FIGURE 11.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 q_t Horizontal Net
 1 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2058$ psf
 Temp = 527 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 12.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 q_t Horizontal Net
 1 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2073$ psf
 Temp = 522 R

46 1323

10 X 10 TO 1/8 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 13.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 Horizontal Net
 q_t 45 in. above lip
 -21.5 in off Tunnel Center Line

Feb 84
 $P_{atm} = 2074$ psf
 Temp = 516 R

46 1323

10 X 10 TO 1/4 INCH 7 X 10 INCHES
 KLUFFEL & ESSLER CO. MADE IN U.S.A.

FIGURE 14.

VWF Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Horizontal Net
 45 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2055$ psf
 Temp = 523 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KJUFEL & ESSER CO. MADE IN U.S.A.

FIGURE 15.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Horizontal Net
 45 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 525 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 16.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Tunnel Empty
 1 in. above lip
 -27.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2073$ psf
 Temp = 522 R

46 1323

KE 10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 17.

VWT Dynamic Pressure Calibration
 q/q_t vs. Tunnel Span for different q_t
 Tunnel Empty
 1 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2075$ psf
 Temp = 522 R

46 1323

10 X 10 TO 1/4 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 18.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 1 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2074$ psf
 Temp = 520 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 19.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 45 in. above lip
 -27.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 520 R

46 1323

10 X 10 TO INCH 7 X 10 INCHES
 KLUFFEL & SIRC CO MAE USA

FIGURE 20.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 45 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 523 R

FIGURE 21.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 45 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 521 R

FIGURE 22. INDICATED VELOCITY CORRECTED TO AVERAGE TUNNEL VELOCITY

FIGURE 23. TURBULENCE INTENSITY PROFILE (HORIZONTAL NET)

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FIGURE 24. TURBULENCE INTENSITY PROFILE (TUNNEL EMPTY)

TABLE 1. FDL 12-FT WIND TUNNEL

Type	Closed Annular Return
Overall Size	86' high, 56' 8" diameter
Centerline Circuit	
Test Section Type	Open Throat
Test Section Shape	16 Side Polygon
Test Section Dimension	12' Across Inscribed Circle
Test Section Length	15' high
Contraction Ratio	9.9 to 1
Maximum Velocity	102 mph
Maximum Mach Number	0.14
Maximum Dynamic Pressure	25 psf
	1000hp DC Motor, Ward Leonard Speed Control System
Energy Ratio	0.65
Temperature Control	None
Stagnation Temp. Range	Approx. Atmospheric
Operating Pressure Range at Fan Section	Approx. Atmospheric
Air Drive	One 16' Dia. 4-bladed, Fan With Laminated Maple Blades
Drive Shaft	10' Long, 6" dia., Solid Steel Shaft
Maximum Fan RPM	875
Model Support System	Angle-of-Attack (0° - 45°)
Auxiliary Equipment	Position-airspeed-time, data recording 16mm motion picture cameras Electronic data recording equipment
Type of Tests	Parachute Performance Tests Model spinning and Spin Recovery Tests Tests of Free Falling Bodies Free Fall Aerodynamics Aerodynamic Force & Moment Tests
Estimated Cost	\$750,000
Construction Begun	March 1943
Tunnel Put in Operation	May 1944 (limited) August 1945 (full)
Reimbursable Rates (DoD User)	(Civilian Labor) Plus Photographic Materials and Processing for Specific Test Requirements

Table 2. SUMMARY OF MODEL PARAMETERS

MODEL DESIGNATION	1	2	3	4	5	6	7	8	9	10
<u>PARAMETER</u>										
SCALE	1.000	1.000	1.000	1.000	1.000	1.000	1.095	1.108	1.073	1.073
WEIGHT, LBS	1.469	1.307	1.732	1.736	2.065	2.061	2.051	2.007	2.140	2.140
I_{XX} , FT-LB-SEC ² X10 ⁴	7.500	6.671	8.837	8.859	10.54	10.52	12.55	12.57	12.58	12.57
I_{YY} , FT-LB-SEC ² X10 ⁴	4.758	4.232	5.607	5.620	6.686	6.672	7.960	7.974	7.982	7.977
I_{ZZ} , FT-LB-SEC ² X10 ⁴	5.074	4.513	5.979	5.993	7.130	7.115	8.488	8.504	8.511	8.505
SPECIFIC GRAVITY, S.G.	1.402	1.247	1.652	1.656	1.970	1.966	1.490	1.407	1.653	1.652
EPOXY COMPOUND (REN PLASTICS) RP	1710	1710	4033	4033	3260	3260	1710	1710	4033	4033

Table 3. TEST RUN LOG

MODEL NUMBER	LAUNCH* METHOD	TIME	TEST CONDITIONS	TUNNEL CONFIGURATION	COMMENTS
—	—	5 MAR 84	--		Preliminary Testing Data
9	1	0847	P _{atm} =2054psf	Horizontal & Vertical Safety Nets	
9	2	6 MAR 84	Temp=509 R		
9	3				
9	4				
9	5				
9	6				
9	7				
7	1		"	"	"
7	2				
7	3				
7	4				
7	5				
7	6				
7	7				
8	1		"	"	"
8	2				
8	3				
8	4				
8	5				
8	6				
8	7				
2	1		"	"	"
2	2				
2	3				
2	4				
2	5				
2	6				
2	7				
1	1		"	"	"
1	2				
1	3				
1	4				
1	5				
1	6				
1	7				

* See last page of Table 3.

Table 3. Continued

MODEL NUMBER	LAUNCH* METHOD	TIME	TEST CONDITIONS	TUNNEL CONFIGURATION	COMMENTS
3 3 3 3 3 3 3	1 2 3 4 5 6 7	1301 6 MAR 84	$P_{atm}=2055\text{psf}$ Temp=523 R	Horizontal & Vertical Safety Nets	Data
5 5 5 5 5 5 5	1 2 3 4 5 6 7		"	"	"
9 7 8 2 1 3 5	8 8 8 8 8 8 8	1530 6 MAR 84	"	"	High Speed Photography 100 <u>frames</u> sec
--	--	0850 7 MAR 84	--	--	Demonstration to INSRP Reentry Subpanel
2 2	1 2	1010 7 MAR 84	$P_{atm}=2070\text{psf}$ Temp=520 R	Vertical Safety Net	Data
5 5	1 2		"	"	"
9 9	1 2	1056 7 MAR 84	"	"	"

* See last page of Table 3.

Table 3. Continued

*LAUNCH METHOD	SIDE NORMAL TO FLOW	INDUCED ROTATION
1	-X-axis	--
2	+X-axis	--
3	-X-axis	-Rolling Moment
4	+X-axis	+Rolling Moment
5	-X-axis	+Rolling Moment
6	+X-axis	-Rolling Moment
7	+Y or Z-axis	--
8	+X-axis	+Pitching Moment

Table 4. MODEL ORIENTATION DESIGNATION

SIDE	SYMBOL	COLOR	INFORMATION
X-axis	--	black	model number
-X-axis	--	black	scale and I_{xx} values
Y-axis	circle	red	--
-Y-axis	--	--	--
Z-axis	triangle	green	--
-Z-axis	square	yellow	--

Also see FIG. 7.

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DE84 011065

WENDELL M. BAKER II, 1LT, USAF
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3. Test Run Log
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NOMENCLATURE

$I_{xx}, I_{yy},$	moments of inertia about the X, Y, and Z - axis,
I_{zz}	respectively
P_{atm}	atmospheric pressure
q	dynamic pressure, reference: rake system probe
q_t	dynamic pressure, reference: tunnel pitot-static tube
R	radius location
$R\phi$	tunnel radius, 6 foot
$S.G.$	specific gravity
$Temp$	temperature in test section
V_{avg}	average velocity, reference: rake system
V_{ind}	indicated velocity, reference: velocity meter
V_t	tunnel velocity, reference: tunnel pitot-static tube
ρ	density of air

1.0 INTRODUCTION

The work reported herein was conducted by the Aeromechanics Division of the Flight Dynamics Laboratory (AFWAL/FIM) located at Wright-Patterson Air Force Base (W-PAFB), Ohio. The test was sponsored by the U. S. Department of Energy, Office of Space Nuclear Projects, Washington D. C. for Johns Hopkins University, Applied Physics Laboratory (APL), Laurel, Maryland, under Job Order Number DOE08401. AFWAL/FIM was reimbursed by DOE for this test.

Project engineers were E. F. Lucero and J. C. Hagan from APL (a Navy contractor providing work for DOE under a DOE/Navy agreement). The test was conducted in the 12 foot Vertical Wind Tunnel (VWT) under the direction of the Experimental Aerodynamics Group and the support of the Experimental Engineering Branch.

The purpose of the test was to obtain statistical information on the dynamics of the General Purpose Heat Source (GPHS) module at terminal speeds. Models were designed to aerodynamically and dynamically represent the GPHS module. Normal and high speed photographic coverage documented the motion of the models. For a general description and purpose of the GPHS modules, refer to references 1 and 2.

This report documents test parameters and techniques for the free-spin tests. It does not include data analysis, which is beyond the scope of this report.

2.0 APPARATUS

2.1 TEST FACILITY

The Air Force Flight Dynamics Laboratory 12 foot Vertical Wind Tunnel is an atmospheric pressure, annular return, closed circuit wind tunnel with an open throat twelve feet in diameter. The airflow is directed vertically upward through the test section. The velocity range of the tunnel is from 0 to 150 ft/sec.

A 1000 horsepower variable - speed DC motor drives the four-bladed fan at speeds between 0 and 875 RPM. A general diagram of the tunnel is shown in Figures 1 and 2. See Table 1 for additional information about the tunnel and its capabilities.

2.2 TEST ARTICLE

The 4950th Test Wing Zone Shop (WPAFB, Ohio) fabricated two sets of GPHS module models and duplicates. One set of models simulates the moments of inertia of the GPHS module, but have different weights and scales. The second set are full scale models, but have different weights and moments of inertia. The GPHS module is described in Figure 3.

Required model weights were calculated based on the wind tunnels maximum speed of 137 ft/sec (with a safety net present). Although this is slightly lower than the terminal velocity of the GPHS module (165 ft/sec), the aerodynamic coefficients should remain constant. For further information on the procedures used to arrive at the desired model designs, refer to Reference 3.

To meet design specifications, the models were homogeneous. Epoxy casting compounds were selected for the model material because of their range in specific gravities and their ease in being casted homogeneously. Three materials from REN Plastics were chosen because of their availability, machinability, and casting properties.

A total of 10 models were fabricated, 6 having constant scale (Models 1-6) and 4 having constant moments of inertia (Models 7-10). A summary of the model parameters is given in Table 2. Refer to Figure 3 for dimensions of the full scale model. The set of models simulating the moments of inertia of the GPHS module, but having different scales, are shown in Figure 4. Figures 5 and 6 are photographs of the two sets of models along with their duplicates.

The models were first casted and then machined to the required dimensions. After casting, the models did contain some small voids; however, the models did appear to be homogeneous in nature. The hardener to resin ratio for the RP-1710 material was varied to improve its casting properties; however, this caused the specific gravity to vary slightly.

2.3 INSTRUMENTATION

Photographic coverage of the free-flight motion of the GPHS models was recorded on film with a high speed camera. Most test sequences were shot at a normal 24 frames/second. However, on some test sequences, when the models were more dynamic, their motion was recorded at 100 frames/second. A video system was also used to record the motion of the models and provide a quick playback capability.

Test parameters for this experiment included velocity, temperature, and atmospheric pressure. Velocity was measured by a velocity meter located 3 feet below the test section lip and 3.75 inches from the tunnel wall. A digital light display of the velocity reading was located in the test section. Prior to a test sequence the velocity reading was recorded on film. Another digital display in the test section was used to identify the model being tested and the launch method. This was also recorded on film. Temperature was measured using a standard thermocouple and atmospheric pressure was measured using a mercury column.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

The majority of the test runs were conducted with both horizontal and vertical safety nets installed in the test section. The safety nets protected personnel and equipment from being struck by the model. The nets also protected the models from being severely damaged since they were susceptible to fracturing. Care was taken with the models to obtain the greatest number of test runs before the models became unusable. A duplicate was made in case a total failure occurred.

The vertical safety net has a 1 inch mesh and the horizontal safety net has a 3/4 inch mesh of 3/32 inch diameter nylon. The vertical net stretches from the tunnel lip to the diffuser mouth. Three slits are present in the vertical net to act as windows. Velcro strips are used to fasten them securely to the net. This net was present for the entire test. The horizontal safety net attaches to the tunnel lip and is then tied down to the tunnel at various locations. The final effect of being tied down is that a 3 foot diameter section of the net, at the tunnel center-line, is 2 feet below the tunnel lip.

A limited number of test runs were conducted without the horizontal safety net. This allowed for a greater maximum velocity (150 ft/sec) and better quality flow. However, without the horizontal net present it was difficult to retrieve the model quickly since it would come to rest at the honeycomb section.

The test was conducted at velocities ranging from 105 to 140 ft/sec. Test conditions are summarized along with the test sequence in Table 3.

3.1.1 TEST SEQUENCE

Testing was conducted between 5 and 7 March 1984. The first day of testing was devoted to preliminary work and data was taken the following two days. Symbols were painted on the models to distinguish their flight orientation. A description of the symbol system used is given in Figure 7 and Table 4.

Since the models made from RP-1710 varied in specific gravity, duplicates (Models 2, 8) were considered as independent test models. Therefore, models 1, 2, 3, 5, 7, 8 and 9 were tested.

The tunnel was first brought up to speed, and then the models were hand-launched into the airstream from a window in the vertical net. Because of the dynamics of the model in free-flight, it was necessary to adjust the tunnel velocity during a test run to keep the model floating. The models were subjected to several different initial conditions for the test, always hand-launched. A summary of the actual test activities is found in Table 3.

3.2 DATA CORRECTIONS

3.2.1 TEST SECTION FLOW

A dynamic pressure calibration was completed prior to the GPHS test using a 24 pitot-static probe rake system. Data was collected at several locations, with and without the horizontal safety net. The calibration set-up and test locations are shown in Figures 8 and 9. Figures 10 through 21 are plots of the dynamic pressure ratio versus tunnel span. The tunnel dynamic pressure was referenced to another pitot-static tube located 3 foot below the tunnel lip and 3.75 inches from the tunnel wall.

The velocity meter was calibrated to the tunnel pitot-static tube after the test. An average tunnel velocity was determined by averaging the data from the probes at a certain height (1 in. or 45 in.) and assuming a 10 foot diameter useable tunnel testing area. These plots are shown in Figure 22.

The VWT has a comparatively high level of turbulence intensity, especially with the horizontal safety net installed. A turbulence survey was conducted in 1979 using a hot-wire anemometer. Turbulence intensities were measured 7 feet above the tunnel lip and are shown in Figures 23 and 24.

3.3 UNCERTAINTY OF MEASUREMENT

3.3.1 TEST ARTICLES

Although the test models did contain some small voids, they appeared homogeneous in nature. A tolerance of ± 0.002 inches was kept on the major dimensions of the GPHS models and the tolerance for the chamfers was ± 0.004 inches. The edges of the test models were rounded with a hand file to a very small radius. The models were weighed to within ± 0.0005 pounds.

3.3.2 TEST SECTION FLOW

The airflow quality with the horizontal safety net present is much less than that when the tunnel is empty. Therefore, identical test runs were repeated without the horizontal safety net to visually determine if the change in air flow quality would change the free-flight motion characteristics of the GPHS model.

Turbulence can cause the flow pattern in a tunnel to be similar to the flow pattern in free air at a higher Reynolds number. However, the aerodynamic coefficients of the GPHS module should remain constant around the same Reynolds number. For a further discussion on this subject, refer to Reference 4.

4.0 DATA PACKAGE PRESENTATION

The data package contained (1) 16mm high speed film, (2) video tape recordings, and (3) test article photographs. The entire package was delivered to Messrs E. F. Lucero and J. C. Hagan, Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland. Requests for these data should be submitted to Messrs Lucero and Hagan. The originals are on file at the Vertical Wind Tunnel.

REFERENCES

1. Bennett, G. L., Lombardo, J. J., and Rock, B. J. "Development and Use of Nuclear Power Sources for Space Applications". The Journal of the Astronautical Sciences, Vol. XXIX, No. 4, pp. 321-342, Oct - Dec 1981.
2. Bennett, G. L., Lombardo, J. J., and Rock, B. J. "U. S. Radioisotope Thermoelectric Generator, Space Operating Experience". Presented at the 18th IECE Conference, 21-26 August 1983.
3. APL/JHU Letter ANSP-241, "Design of Models for Wind Tunnel Simulation of GPHS Module Motion at Terminal Speeds". E. F. Lucero to J. C. Hagan.
4. Pope, M. Wind-Tunnel Testing. New York: John Wiley & Sons, Inc., 1958.

FIGURE 1.

VERTICAL WIND TUNNEL

1 / 120 SCALE .

Figure 2. Vertical Wind Tunnel
3-D View

Dimensions in inches

Weight = 3.19 lbs

$I_{xx} = 12.48 \times 10^{-4}$ ft - lb_f-sec²

$I_{yy} = 8.01 \times 10^{-4}$ ft - lb_f-sec²

$I_{zz} = 8.52 \times 10^{-4}$ ft - lb_f-sec²

figure 3. GPHS module (scale = 1.0)
(models 1-6)

(A) MODEL 7

(B) MODEL 8

(C) MODEL 9

(D) MODEL 10

DIMENSIONS IN INCHES

FIGURE 4. GPHS MODULE (MOMENTS OF INERTIA = CONSTANT)

Figure 5. GPMS Models 1-6
Scale = 1.0

Figure 6. GPHS Models 7-10
Moments of Inertia = constant

VWT
PROJECT
NUMBER
DOE08401
GPHS FREE
FLIGHT TEST
DAYS 5→7 MAR84

Figure 7. Model Orientation Designation
Models 1-6

15

Diagram illustrating the rake and probe positions for a 24-tooth gear. The diagram shows 24 vertical lines representing teeth, numbered 1 to 24. A central vertical line is labeled "RAKE POSITION". To the right, a dimension line indicates a distance of 6 inches from the center to the first tooth, and another dimension line indicates a distance of 3 1/2 inches between the first and second teeth.

FIGURE 9.

VERTICAL WIND TUNNEL FLOW FIELD SURVEY RAKE AND PROBE POSITIONS

DATA LOCATIONS USED FOR THE DYNAMIC PRESSURE CALIBRATION

FIGURE 10.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Horizontal Net
 1 in. above lip
 -27.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2058 \text{ psf}$
 Temp = 525 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 11.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Horizontal Net
 1 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2058$ psf
 Temp = 527 R

46 1323

K&E 10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 12.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 q_t Horizontal Net
 1 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2073$ psf
 Temp = 522 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 13.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Horizontal Net
 45 in. above lip
 -21.5 in off Tunnel Center Line

Feb 84
 $P_{atm} = 2074$ psf
 Temp = 516 R

FIGURE 14.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 Horizontal Net
 45 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2055$ psf
 Temp = 523 R

FIGURE 15.

VWF Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 q_t Horizontal Net
 45 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 525 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 FEIJ FEL & ESSER CO. MADE IN U.S.A.

FIGURE 16.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 1 in. above lip
 -27.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2073$ psf
 Temp = 522 R

46 1323

1/2" 12 X 12 TO 1" INCH 7 X 10 INCHES
 KEL EL & E SER CO MADE IN U.S.A.

FIGURE 17.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Tunnel Empty
 1 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2075$ psf
 Temp = 522 R

46 1323

10 X 10 TO 1/4 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 18.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 1 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2074$ psf
 Temp = 520 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 19.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 45 in. above lip
 -27.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 520 R

FIGURE 20.

VWT Dynamic Pressure Calibration
 q vs. Tunnel Span for different q_t
 q_t Tunnel Empty
 45 in. above lip
 -3.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 523 R

46 1323

10 X 10 TO 1/2 INCH 7 X 10 INCHES
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 21.

VWT Dynamic Pressure Calibration
 $\frac{q}{q_t}$ vs. Tunnel Span for different q_t
 Tunnel Empty
 45 in. above lip
 20.5 in. off Tunnel Center Line

Feb 84
 $P_{atm} = 2054$ psf
 Temp = 521 R

46 1323

10 X 10 TO INCH 7 X 10 INCHES
 K DIFFL & ESF Q CO WALT N USA

FIGURE 22. INDICATED VELOCITY CORRECTED TO AVERAGE TUNNEL VELOCITY

FIGURE 23. TURBULENCE INTENSITY PROFILE (HORIZONTAL NET)

3/17

FIGURE 24. TURBULENCE INTENSITY PROFILE (TUNNEL EMPTY)

TABLE 1. FDL 12-FT WIND TUNNEL

Type	Closed Annular Return
Overall Size	86' high, 56' 8" diameter
Centerline Circuit	
Test Section Type	Open Throat
Test Section Shape	16 Side Polygon
Test Section Dimension	12' Across Inscribed Circle
Test Section Length	15' high
Contraction Ratio	9.9 to 1
Maximum Velocity	102 mph
Maximum Mach Number	0.14
Maximum Dynamic Pressure	25 psf
	1000hp DC Motor, Ward Leonard Speed Control System
Energy Ratio	0.65
Temperature Control	None
Stagnation Temp. Range	Approx. Atmospheric
Operating Pressure Range at Fan Section	Approx. Atmospheric
Air Drive	One 16' Dia. 4-bladed, Fan With Laminated Maple Blades
Drive Shaft	10' Long, 6" dia., Solid Steel Shaft
Maximum Fan RPM	875
Model Support System	Angle-of-Attack (0° - 45°)
Auxiliary Equipment	Position-airspeed-time, data recording 16mm motion picture cameras Electronic data recording equipment
Type of Tests	Parachute Performance Tests Model spinning and Spin Recovery Tests Tests of Free Falling Bodies Free Fall Aerodynamics Aerodynamic Force & Moment Tests
Estimated Cost	\$750,000
Construction Begun	March 1943
Tunnel Put in Operation	May 1944 (limited) August 1945 (full)
Reimbursable Rates (DoD User)	(Civilian Labor) Plus Photographic Materials and Processing for Specific Test Requirements

Table 2. SUMMARY OF MODEL PARAMETERS

MODEL DESIGNATION	1	2	3	4	5	6	7	8	9	10
<u>PARAMETER</u>										
SCALE	1.000	1.000	1.000	1.000	1.000	1.000	1.095	1.108	1.073	1.073
WEIGHT, LBS	1.469	1.307	1.732	1.736	2.065	2.061	2.051	2.007	2.140	2.140
$I_{XX}, \text{FT-LB-SEC}^2 \times 10^4$	7.500	6.671	8.837	8.859	10.54	10.52	12.55	12.57	12.58	12.57
$I_{YY}, \text{FT-LB-SEC}^2 \times 10^4$	4.758	4.232	5.607	5.620	6.686	6.672	7.960	7.974	7.982	7.977
$I_{ZZ}, \text{FT-LB-SEC}^2 \times 10^4$	5.074	4.513	5.979	5.993	7.130	7.115	8.488	8.504	8.511	8.505
SPECIFIC GRAVITY, S.G.	1.402	1.247	1.652	1.656	1.970	1.966	1.490	1.407	1.653	1.652
EPOXY COMPOUND (REN PLASTICS) RP	1710	1710	4033	4033	3260	3260	1710	1710	4033	4033

Table 3. TEST RUN LOG

MODEL NUMBER	LAUNCH* METHOD	TIME	TEST CONDITIONS	TUNNEL CONFIGURATION	COMMENTS
—	—	5 MAR 84	--		Preliminary Testing Data
9	1	0847	P _{atm} =2054psf	Horizontal & Vertical Safety Nets	
9	2	6 MAR 84	Temp=509 R		
9	3				
9	4				
9	5				
9	6				
9	7				
7	1		"	"	"
7	2				
7	3				
7	4				
7	5				
7	6				
7	7				
8	1		"	"	"
8	2				
8	3				
8	4				
8	5				
8	6				
8	7				
2	1		"	"	"
2	2				
2	3				
2	4				
2	5				
2	6				
2	7				
1	1		"	"	"
1	2				
1	3				
1	4				
1	5				
1	6				
1	7				

* See last page of Table 3.

Table 3. Continued

MODEL NUMBER	LAUNCH* METHOD	TIME	TEST CONDITIONS	TUNNEL CONFIGURATION	COMMENTS
3 3 3 3 3 3 3	1 2 3 4 5 6 7	1301 6 MAR 84	$P_{atm}=2055\text{psf}$ Temp=523 R	Horizontal & Vertical Safety Nets	Data
5 5 5 5 5 5 5	1 2 3 4 5 6 7		"	"	"
9 7 8 2 1 3 5	8 8 8 8 8 8 8	1530 6 MAR 84	"	"	High Speed Photography 100 <u>frames</u> sec
--	--	0850 7 MAR 84	--	--	Demonstration to INSRP Reentry Subpanel
2 2	1 2	1010 7 MAR 84	$P_{atm}=2070\text{psf}$ Temp=520 R	Vertical Safety Net	Data
5 5	1 2		"	"	"
9 9	1 2	1056 7 MAR 84	"	"	"

* See last page of Table 3.

Table 3. Continued

*LAUNCH METHOD	SIDE NORMAL TO FLOW	INDUCED ROTATION
1	-X-axis	--
2	+X-axis	--
3	-X-axis	-Rolling Moment
4	+X-axis	+Rolling Moment
5	-X-axis	+Rolling Moment
6	+X-axis	-Rolling Moment
7	+Y or Z-axis	--
8	+X-axis	+Pitching Moment

Table 4. MODEL ORIENTATION DESIGNATION

SIDE	SYMBOL	COLOR	INFORMATION
X-axis	--	black	model number
-X-axis	--	black	scale and I_{xx} values
Y-axis	circle	red	--
-Y-axis	--	--	--
Z-axis	triangle	green	--
-Z-axis	square	yellow	--

Also see FIG. 7.

Figure 5. GPHS Models 1-6
Scale = 1.0

Figure 6. GPHS Models 7-10
Moments of Inertia = constant

VWT
PROJECT
NUMBER
DOE08401
GPHS FREE
FLIGHT TEST
DAYS 5→7 MAR84

Figure 7. Model Orientation Designation
Models 1-6