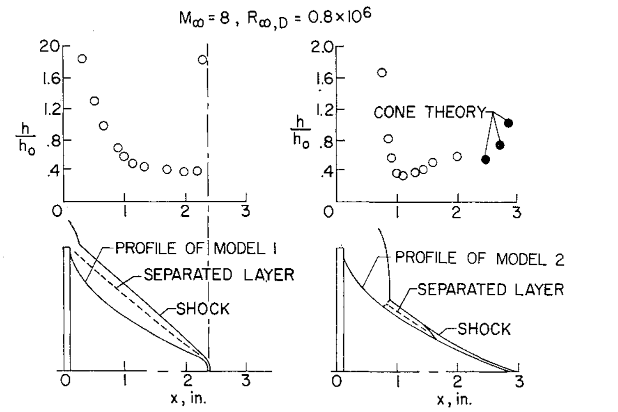

Fig. 4 Heat-transfer distributions on bell-shaped configurations.

error. However, the difference, $A - T_i$, is not always large, so that the error in h due to the error in A becomes larger for coating materials having smaller values of A. Therefore, it is essential to cool the model to near room temperature for each run, particularly for coatings with low values of A. Also, since the model must be made from good insulating material, care must be taken to avoid errors due to radiation from external sources to the model.

Experimental Results

The data presented herein were obtained in the Langley Mach 8, variable-density tunnel, which is described briefly in Ref. 5. A 4-in.-diam hemisphere was tested at three values of $R_{\infty,D}$. The 200°F phase-change material was used. The h distributions obtained are shown in Fig. 2 and are compared with a theory for which a modified Newtonian pressure distribution was used with the method of Ref. 6 to determine the stagnation-point value and the method of Ref. 7 to determine the distribution. Agreement with theory is relatively good except for the data nearest the stagnation point for each curve. These data correspond to the earliest time (0.2 sec) for which data could be reduced; therefore, the error in h due to any error in determining the initial time is large.

Two bell-shaped configurations were tested by the phase-change method. They had rather extensive separation regions with reattachment somewhere on the flare. Sample photographs of the phase-change patterns obtained on model 1 are shown in Fig. 3. Notice the sharply defined regions of very low heat-transfer rate just downstream of the nose. The measured heat-transfer coefficients are shown in Fig. 4 as a function of distance and compared with sketches of the flow patterns. In Fig. 4 for the blunt-nosed model, h varies by a factor of 4.5 over a surface distance of only 0.05 in. It is doubtful that heat-transfer rates could be measured accurately by the thermocouple-calorimeter technique in regions subjected to such large gradients. In Ref. 8, the phase-change coating method was used to measure the heating rates in regions near holes, protuberances, and reaction-control jets on a 4-in.-diam model of the Apollo command module. The fine details in heat-transfer distributions obtained in the interference regions of this model are considered noteworthy for such small model dimensions.

It is concluded that this technique can produce quantitative heat-transfer data on arbitrary shapes. It should be useful for complex configurations that would be difficult to instrument with thermocouples and for configurations subjected to interference effects of unknown extent and location.

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Orbital Elements from the Doppler Tracking of Four Satellites

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IN Ref. 1 we presented the initially determined orbital elements from the Doppler tracking of three satellites: 1961 $\alpha\eta$1 at an inclination of 33°, 1962 $\beta\mu$1 at 50°, and 1961 o 1 at 67°. These elements were determined with a model of

Table 1 Orbital elements of 1963 49B

t_p, days since Jan. 0.0	$10^6 e$	$10^4(i-89°)$ Year = 1964	ω degrees	Ω degrees	N
25.00464877	4349	9619	137.393	102.0492	673
29.02228416	4503	9617	128.255	102.0342	727
35.04880728	4681	9593	114.889	102.0096	808
54.02143615	4724	9577	74.004	101.9319	1063
62.05681946	4510	9548	56.303	101.8965	1171
69.05044640	4219	9549	40.264	101.8657	1265
73.06797157	4017	9533	30.615	101.8473	1319
79.01969823	3685	9540	15.549	101.8200	1399
83.03696314	3446	9537	4.648	101.8019	1453
90.02957202	3029	9522	343.720	101.7688	1547
94.04628710	2808	9535	330.182	101.7501	1601
98.06277245	2621	9529	315.525	101.7315	1655
103.93828219	2429	9530	291.877	101.7037	1734
105.05384391	2406	9528	287.189	101.6985	1749
111.89581988	2396	9538	257.767	101.6682	1841
113.01137809	2415	9530	253.064	101.6630	1856
119.92810762	2637	9549	225.199	101.6317	1949
121.04379066	2686	9550	221.103	101.6269	1964
125.06035623	2885	9552	206.861	101.6094	2018
129.00278583	3111	9547	194.076	101.5916	2071
133.01979740	3355	9560	182.002	101.5743	2125
137.03698440	3592	9573	170.779	101.5576	2179
141.05431728	3825	9565	160.265	101.5402	2233
143.88138990	3989	9564	153.161	101.5289	2271
149.01488823	4245	9584	140.901	101.5071	2340
157.05011832	4559	9577	122.629	101.4743	2448

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the earth's gravity field that contained only zonal harmonics through the sixth, with estimates of the nonzonal harmonics of indices (2,2) and (4,1) being added at various times.

These elements, together with the data from which they were determined, have been used to derive an interim model of the gravity field, which includes all nonzonal harmonics through the fourth degree and all zonal harmonics of odd degree through the ninth. To complete this interim model, the zonal harmonics of even degree through the sixth were added.† The purpose of this interim model was to afford a standard basis for redetermining the elements of the three satellites of Ref. 1, plus the satellite 1963 49B with an inclination of 90°. The set of elements derived on this standard basis was then used in a more definitive determination of the gravity field, including all harmonics through the eighth degree, plus a few of higher degree to which one or more of the satellites happened to be particularly sensitive.

The interim model has not been published in its entirety but is available in the internal reports of Refs. 2 and 3. The new model is being prepared for publication.

In this paper, we present a table of orbital elements for the satellite 1963 49B for which no elements have been published previously. These elements were determined with the interim gravity model. They do not begin with the first perigee passage of the satellite ($N = 0$) as did the elements in Ref. 1. We have determined from the early elements of the satellite that it was subject, for perhaps its first 200 revolutions, to a fluctuating force with a maximum value of about 0.5 dyne. We believe that this force was the rate of momentum transfer arising from the sublimation of a plastic material carried on the spacecraft and that the rate fluctuated with varying exposure of the material to sunshine. The elements for this satellite, given in Table 1, began a safe time after it was no longer possible to detect the force by the orbital behavior.

Tables 2–4 give the elements for the three satellites 1961 $\alpha\eta$1, 1962 $\beta\mu$1, and 1961 o 1 that were redetermined with the interim gravity model. We are presenting these new elements because they are considerably more accurate than those published in Ref. 1. The data residuals with the new elements are smaller than with the old elements by a factor that ranges from about 3 for 1962 $\beta\mu$1 to about 10 for 1961 $\alpha\eta$1. The elements given here are those that were used in the more

Table 2 Orbital elements of 1961 $\alpha\eta$1

t_p, days since Jan. 0.0	$10^6 e$	$10^4(i-32°)$	ω degrees	Ω degrees	N
		Year = 1962			
6.76936122	10360	4269	2.655	290.8617	705
8.82509473	10490	4267	18.059	280.6060	733
13.82140299	10748	4260	54.715	255.6935	801
18.81643582	10821	4227	90.792	230.7820	869
21.82814059	10772	4229	112.515	215.7640	910
27.92516116	10469	4271	157.262	185.3546	993
39.82627361	09835	4267	249.053	126.0037	1155
42.32415944	09819	4276	268.920	113.5452	1189
44.82203765	09856	4280	288.748	101.0911	1223
46.80562582	09928	4286	304.391	91.1995	1250
48.78920156	10024	4277	319.974	81.3068	1277
50.77273008	10142	4274	335.326	71.4144	1304
55.47428648	10457	4279	11.021	47.9660	1368
57.45768859	10578	4278	25.755	38.0751	1395
64.80339395	10847	4277	79.221	1.4418	1495
68.77001768	10816	4269	107.819	341.6608	1549
74.79351962	10549	4272	151.794	311.6235	1631
76.77692849	10421	4269	166.574	301.7315	1658
79.49499607	10238	4264	187.141	288.1754	1695
104.91362206	10584	4259	24.577	161.4053	2041
111.52475973	10853	4237	72.781	128.4365	2131
114.53644458	10861	4247	94.476	113.4178	2172
117.76850707	10781	4260	117.818	97.2977	2216
119.45801189	10711	4254	130.097	88.8729	2239
125.77547873	10331	4280	176.968	57.3656	2325
126.87739755	10261	4280	185.314	51.8698	2340
131.43214379	09986	4285	220.553	29.1595	2402
147.81492563	10273	4273	349.216	307.4612	2625
151.78178180	10532	4265	19.034	287.6769	2679
153.76515160	10654	4270	33.658	277.7846	2706
155.52812471	10736	4271	46.545	268.9963	2730
162.80026775	10841	4253	99.129	232.7257	2829
163.82864908	10819	4254	106.552	227.5982	2843
165.81196765	10755	4250	120.924	217.7082	2870
169.77867001	10552	4239	149.994	197.9244	2924
174.03933549	10277	4251	181.871	176.6703	2982
177.78594726	10036	4249	210.705	157.9888	3033
181.82653665	09865	4264	242.423	137.8352	3088
184.76520670	09824	4277	265.783	123.1797	3128

† The values chosen were $10^6 J_2 = 1082.2$, $10^6 J_4 = 1.82$, $10^6 J_6 = -0.11$.

Table 3 Orbital elements of 1962 $\beta\mu$1

t_p, days since Jan. 0.0	$10^6 e$	$10^4(i-50°)$	ω degrees	Ω degrees	N
		Year = 1962			
315.31544208	6388	1287	236.713	14.8938	146
318.31305326	6334	1284	246.592	4.0767	186
320.56128042	6306	1283	254.086	355.9614	216
323.78373061	6288	1283	264.789	344.3326	259
325.95702115	6287	1281	272.049	336.4878	288
330.82815811	6328	1271	288.184	318.9081	353
335.77421421	6418	1280	304.457	301.0583	419
336.29879908	6431	1276	306.197	299.1672	426
338.32216929	6484	1270	312.776	291.8653	453
341.91922541	6594	1275	324.248	278.8821	501
345.29142818	6709	1272	334.821	266.7129	546
348.81346061	6847	1260	345.635	254.0031	593
349.78763709	6884	1258	348.617	250.4877	606
352.78506428	7006	1253	357.596	239.6698	646
354.80831140	7087	1257	3.578	232.3688	673
356.83154545	7164	1254	9.497	225.0672	700
361.85210071	7361	1234	23.886	206.9476	767
		Year = 1963			
3.29629997	7567	1242	41.900	183.6881	853
6.89301201	7667	1236	51.710	170.7078	901
10.26492079	7738	1248	60.867	158.5361	946

Table 4 Orbital elements of 1961 o 1

t_p, days since Jan. 0.0	$10^6 e$	$10^4(i-66°)$	ω degrees	Ω degrees	N
		Year = 1962			
42.03636259	8174	8006	135.763	266.8276	3146
46.00177596	8186	8007	133.079	257.2129	3201
50.03928643	8189	8005	130.352	247.4183	3257
57.03282395	8206	8011	125.587	230.4639	3354
65.03574754	8215	8009	120.213	211.0607	3465
67.05449827	8217	8017	118.841	206.1592	3493
76.06678230	8222	8021	112.731	184.3125	3618
91.92839114	8222	8016	102.004	145.8521	3838
96.03799470	8225	8003	99.254	135.8918	3895
99.06612637	8228	8001	97.246	128.5481	3937
105.91543629	8225	7998	92.534	111.9367	4032
109.01566800	8227	7992	90.498	104.4191	4075
115.07189950	8223	8015	86.355	89.7379	4159
121.05604706	8228	8011	82.350	75.2268	4242
125.02144159	8231	8039	79.685	65.6124	4297
126.89599100	8232	8034	78.425	61.0646	4323
132.01494690	8232	8029	74.961	48.6560	4394
134.03369396	8229	8049	73.620	43.7616	4422
138.93634196	8232	8038	70.249	31.8726	4490
140.01780571	8231	8040	69.489	29.2535	4505
148.02067926	8229	8044	64.119	9.8493	4616
150.90460442	8224	8027	62.221	2.8542	4656
156.02355356	8223	8013	58.764	350.4424	4727
159.05166718	8209	8030	56.735	343.1002	4769
161.93557478	8201	8024	54.755	336.1085	4809
173.90380982	8168	8030	46.654	307.0832	4975
186.01622319	8132	8026	38.411	277.7146	5143

definitive determination of the gravity field and do not necessarily span the useful operating life of the satellite. The count of the anomalistic revolution number N, however, still begins with the first perigee passage.

One word of caution is needed about the use of these elements. The elements describe a precessing ellipse which has the best rms fit to an accurately computed orbit over a time span of 24 hr. The epoch of each set of elements is the last perigee passage before the beginning of the time span. In the fitting process, the elements are assumed constant except for the argument of perigee ω and the longitude of the node Ω, which are assigned constant time derivatives (the precession rates). As a consequence, the semimajor axis a, the eccentricity e, and the inclination i are the averages of these quantities over the time span and to high approximation are the values of these quantities at the center of the time span. Thus they belong to an epoch different from the epoch given in the tables. Further, the derivatives of perigee ω, the node Ω, and the time of perigee t_p themselves belong to the later epoch. If one intends to use these elements for the purpose of studying their variations, the values for ω, Ω, and t_p should be carried forward in time, using their theoretical time derivatives, by an amount equal to 12 hr plus one-half of a period. Since the beginning of a fitting span occurs at random with respect to perigee, this process leaves "noise" in the elements equivalent to the changes in the elements during one-half of a period. It is regretted that we did not realize how significant the changes in the elements within 12 hr can be when we fixed the procedure for fitting the elements.

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Design of a Total Radiation Thermopile Detector

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EFFECTIVE thermal balance testing in a space simulation chamber requires the measurement and control of irradiance (the total radiant power per unit area incident upon the test object). Requirements for a detector to measure irradiance are determined by the spectral content, collimation, and physical arrangement of the radiation sources to be measured. Additional stability requirements are necessary if the detector is to serve also as a feedback transducer in closed-loop control of the radiation sources.

A detector suitable for both measuring and control purposes should possess the following features:

1) It should be small in size so that the shadows produced will not measurably affect test results.

2) Response should be independent of spectral content and angle of incidence of the radiation, and its output should be linear with respect to the magnitude of irradiance. With these characteristics, irradiance measurements can be made of both high- and low-temperature sources with a single calibration constant and without the need for calibration curves.

3) A hemispherical field of view is necessary when measuring the irradiance produced by distributed sources.

4) Zero drift in the detector should be negligible. If appreciable zero drift were present, use of the detector as a feedback transducer would be seriously impaired.

5) Design should be such that detectors can be readily produced with similar sensitivity factors and response times. This is particularly important if several detectors are to be integrated into a multiple-channel radiation control system.

A detector has been developed which incorporates a thermopile with a blackened receiver to achieve a spectrally uniform and linear output signal. Zero drift is made negligible by electrically maintaining the thermopile reference junctions at a constant temperature.

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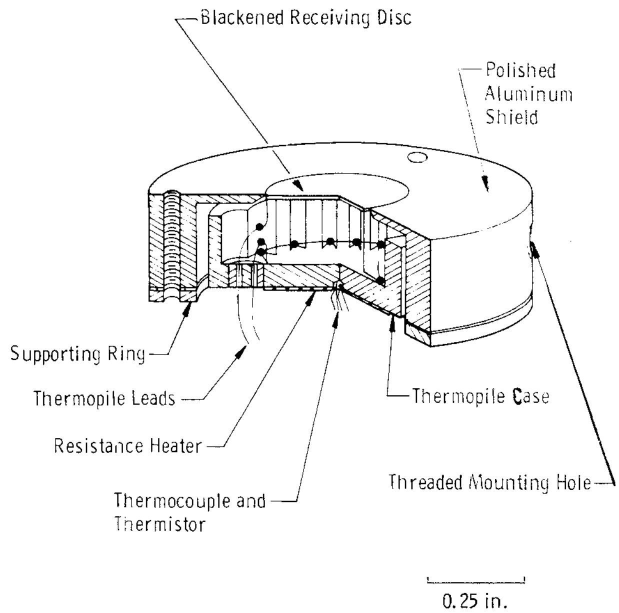

Fig. 1 Assembled detector.

Description of Detector and Case Temperature Controller

Cutaway and exploded views of the detector are shown in Figs. 1 and 2. The receiving disk is coated with optical black lacquer and absorbs approximately 0.98 of all incident radia-

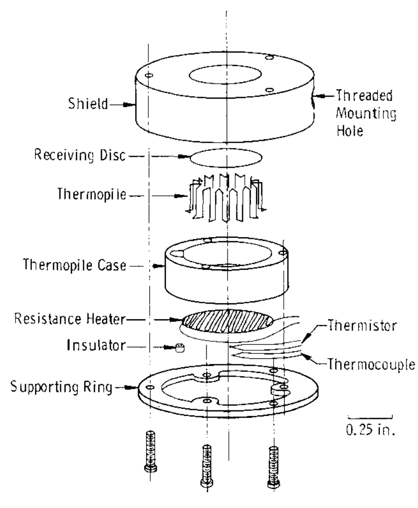

Fig. 2 Thermopile radiation detector with heated reference junctions.