DEPARTMENT OF
AERONAUTICS AND ASTRONAUTICS

CAMBRIDGE MASSACHUSETTS 02139
ROOM 617 253-
TELEX 92-1473 CABLE MIT CAM

WRITTEN QUALIFYING EXAMINATION

FOR

DOCTORAL CANDIDATES

Thursday, February 26, 1987 33-319 1:00 p.m. - 5:00 p.m.

• CLOSED BOOKS AND NOTES •

Answer six (6) but no more (and no less) of the following 18 questions.*

Please answer each question on a separate sheet (or sheets). Do not put the answers to different questions on the same sheet of paper!

Be sure that your name appears on every sheet of paper you turn in.

An announcement will be made when the results are available. Results should be available within 2 weeks.

Oral Examinations, if required, will be arranged individually.

*The questions are variously in the disciplines of

guidance and control	propulsion	structures
fluids	thermodynamics	bio-engineering
systems	dynamics	physics
airplane mechanics		

Question 1.

As the performance analyst for Rockdonnel-Marietta Aircraft, you have been given the following characteristics for the new commercial transport your company is designing:

Total take-off mass = 100,000 kg

Fuel mass = 35,000 kg

Specific Fuel Consumption = $.03\left[\frac{kg/hr}{N}\right]$

Span (b) = 30 m

Max thrust = 250,000 N

Span factor (e) = 1.0

$\left(C_{L_{max}}\right)_{\text{no flaps}}$ = 1.2

$\left(C_{L_{max}}\right)_{\text{flaps}}$ = 2.0

$\rho_{\text{sea level}}$ = 1.225 $\frac{kg}{m^3}$

ρ_{cruise} = .364 $\frac{kg}{m^3}$

Wing Area = 180 m^2

Parasite drag coefficient $\left(C_{D_0}\right)$ = .05

1.) **Find the aspect ratio and wing loading.**

2.) **Find the stall speeds:**
  a.) **with flaps at sea level.**
  b.) **without flaps at cruise altitude.**

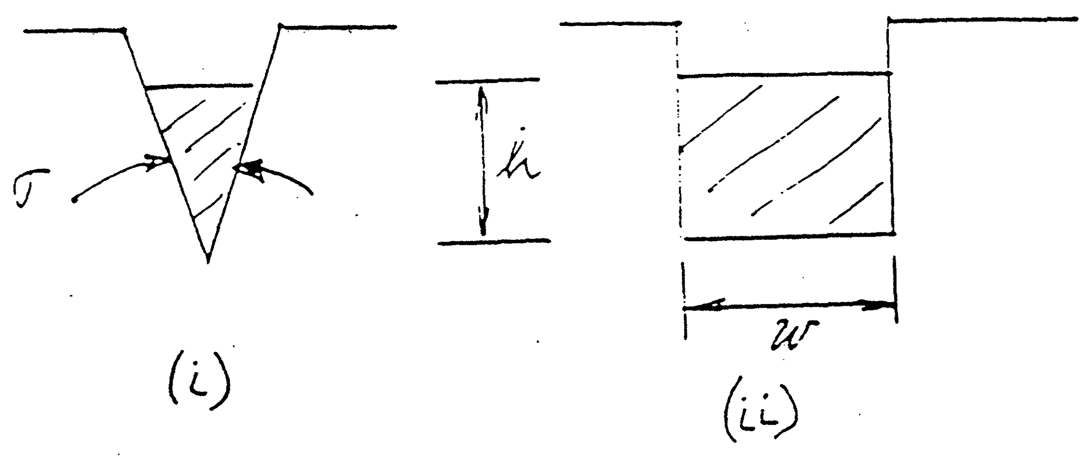
3.) **Find the maximum velocity of the aircraft at cruise conditions and max weight.**

4.) **Find the range of the aircraft at maximum velocity cruise.**

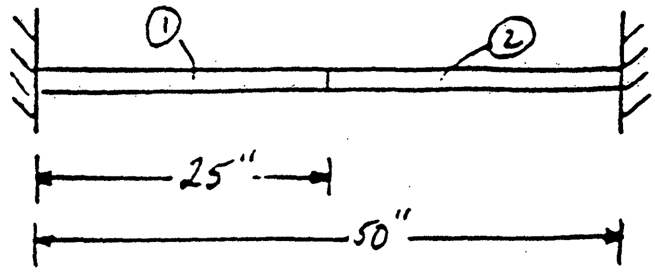
Question 2.

Consider the flow through a spillway, i.e., a notched cutout in a vertical wall through which liquid flows from a reservoir. Typical notches are sketched below. Assume the height h is referred to a reservoir level "far" from the notch, and that the reservoir volume is extremely large.

Determine the functional form for the mass flow rate that exits through the notch [for each of the notches (i) and (ii)]. Be sure to state all the parameters needed to define the problem.



Question 3.



A 50 inch long beam is made of 2 sections each 25 inches long and with a square cross-section of 1 inch to a side. Each section is made of a different isotropic material. The materials both have the same modulus of 10 msi but posess different Poisson's ratios and coefficients of thermal expansion:

Material 1	Material 2
$\nu = 0.25$	$\nu = 0.35$
$\alpha = 5\times10^{-6}/°F$	$\alpha = 15\times10^{-6}/°F$

The beam is subject to a constant temperature change of ΔT.

(a) If the joint between the two sections is joined perfectly and ideally, at what value of ΔT will buckling occur?

(b) If the joint between the two sections is simply one of frictionless contact, at what value of ΔT will buckling occur?

NOTE: Ignore any eccentricities and imperfections and calculate the bifurcation load.

Question 4.

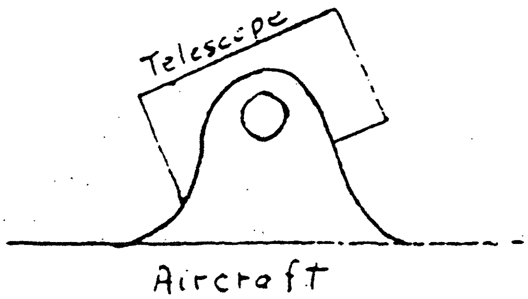
Electric propulsion has the apparent advantage over other forms of propulsion that the exit velocity of the particles that make up the propellant is limited only by the onboard power supply. However, the thrust per unit area of an electric propulsion system is limited by the buildup of space charge. Derive the expression for the thrust per unit area subject to space charge limitations and discuss means of mitigating this limitation.

Question 5.

During takeoff roll, the thrust for a transport aircraft is given by $T=T_0 \cdot e^{-kv}$ where T_0=static thrust, V=airspeed (assume zero wind). The aircraft drag in a zero lift condition is given by $D=D_0 \cdot V^2$ where D_0 is a drag coefficient. If the takeoff is aborted, the reverse thrust and braking action provide a constant braking force, B. If the aircraft mass is m, and the runway length available is S, derive an expression for the maximum decision speed, V_1 (maximum speed at which the takeoff can either be continued or stopped within the available runway).

Question 6.

A telescope is mounted to an aircraft through a gimbal arrangement so it can track target objects and stabilize against aircraft motion. Consider just one axis of stabilization. You may suppose for this exercise that the center of mass of the telescope is on the gimbal axis and that the line of sight to the target is in a fixed direction.



The error angle, the angle between the centerline of the telescope and the line of sight to the target, is available from a processor operating on the data recorded by the telescope. A torque motor drives the telescope relative to the gimbal frame; the torque motor characteristic is

$$T_M = K_1 e - K_2 \dot{\theta}_{AT}$$

where

T_M = torque motor torque

e = applied voltage

$\dot{\theta}_{AT}$ = angular rate of the telescope relative to the aircraft

Suppose that the initial control law is simple proportional feedback of the error angle to voltage applied to the torque motor.

1.) What is the transfer function from aircraft motion to telescope error angle?

2.) What is the steady state error angle in response to a constant aircraft angular rate?

3.) If the answer to (2) is nonzero, suggest the form of a controller such that the steady state error angle due to a constant aircraft angular rate is zero, and show that the resulting system has this characteristic.

Question 7.

The kinetic energy efficiency η_K of a supersonic diffuser is defined as the ratio of the gas kinetic energy obtainable by re-expanding the gas to ambient pressure to the inlet gas kinetic energy. How is η_K related to the total pressure loss parameter, $\pi_d = \frac{\text{Total pressure after diffuser}}{\text{Total pressure before diffuser}}$ and to the inlet Mach number?

Question 8.

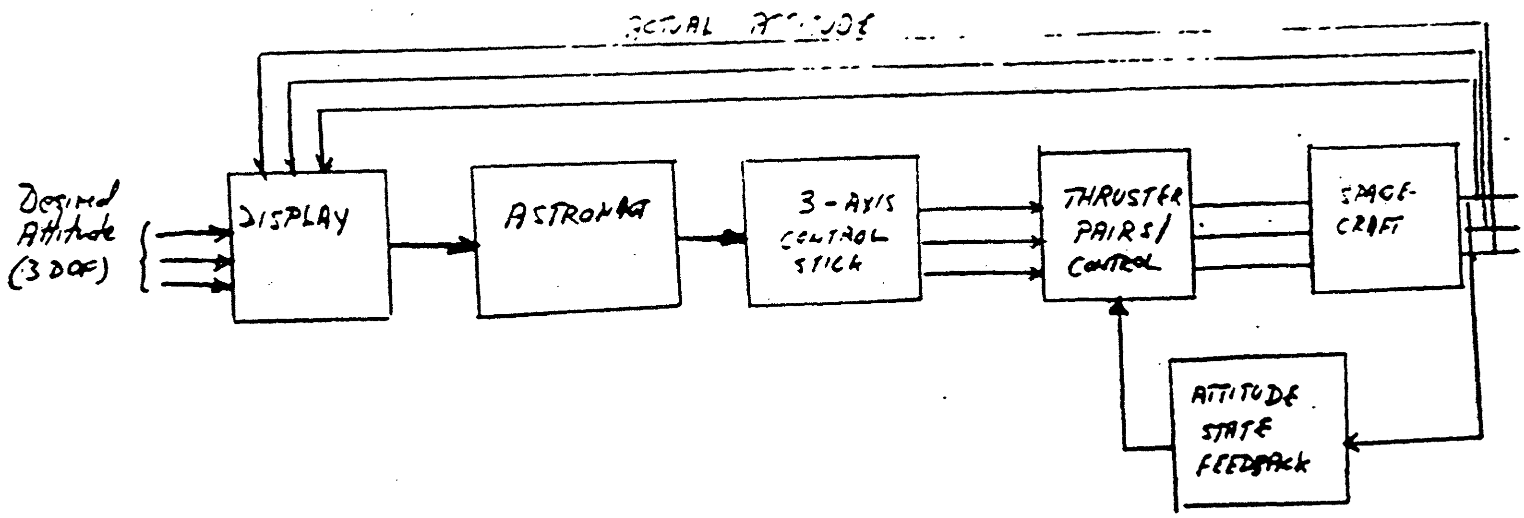
An astronaut may have the task of backup attitude controller to adjust the orientation of a vehicle prior to approach for docking with a very slowly spinning space station. He has 3 pairs of orthogonal, body-fixed and continuously variable thrusters to control.

1.) Sketch a display for him or her to observe.

2.) From the astronaut viewpoint what is the "ideal" controlled element transfer function?

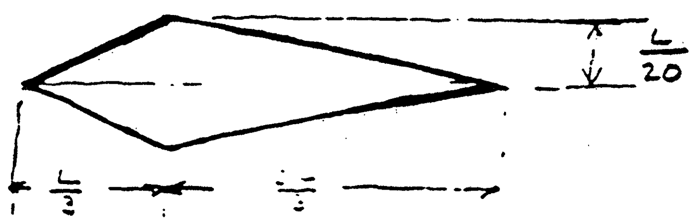
3.) What quantities should be fed back from the vehicle to the thruster control, and how should they be measured?

4.) What would happen if the attitude state feedback were disconnected?

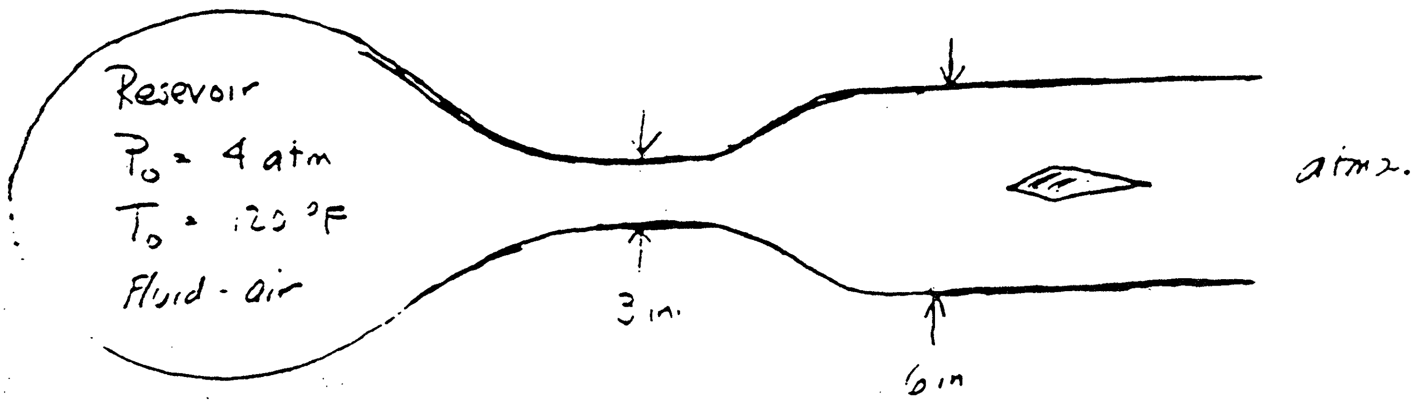


Question 9.

A <u>two-dimensional</u> wedge shape strut of the following geometry



is to be tested in the supersonic wind tunnel sketched below to determine aerodynamic heat rates.



The test engineers need the following questions answered in order to design the model. You may use the attached one-dimensional flow tables.

1.) What supersonic test section Mach number(s) can be obtained in this wind tunnel?

2.) What is a reasonable estimate for the longest model which can be tested without being contaminated by wave reflections from the walls?

3.) What will be the drag force (per unit span -- or depth into the paper) for the largest model which can be tested.

<u>BONUS</u>: For this largest model, will the tunnel be able to "start"? If not, how can the model be changed to permit the tunnel to "start"?

(Please note: Table on next page)

Problem 9, continued.

Parameters for Normal Shock Wave Flow

M_{1n}	p_2/p_1	ρ_2/ρ_1	T_2/T_1	a_2/a_1	p^0_2/p^0_1	M_2 for Normal Shocks Only
1.00	1.000	1.000	1.000	1.000	1.0000	1.0000
1.01	1.023	1.017	1.007	1.003	1.0000	.9901
1.02	1.047	1.033	1.013	1.007	1.0000	.9805
1.03	1.071	1.050	1.020	1.010	1.0000	.9712
1.04	1.095	1.067	1.026	1.013	.9999	.9620
1.05	1.120	1.084	1.033	1.016	.9999	.9531
1.06	1.144	1.101	1.039	1.019	.9998	.9444
1.07	1.169	1.118	1.046	1.023	.9996	.9360
1.08	1.194	1.135	1.052	1.026	.9994	.9277
1.09	1.219	1.152	1.059	1.029	.9992	.9196
1.10	1.245	1.169	1.065	1.032	.9989	.9118
1.11	1.271	1.186	1.071	1.035	.9986	.9041
1.12	1.297	1.203	1.078	1.038	.9982	.8966
1.13	1.323	1.221	1.084	1.041	.9978	.8892
1.14	1.350	1.238	1.090	1.044	.9973	.8820
1.15	1.376	1.255	1.097	1.047	.9967	.8750
1.16	1.403	1.272	1.103	1.050	.9961	.8682
1.17	1.430	1.290	1.109	1.053	.9953	.8615
1.18	1.458	1.307	1.115	1.056	.9946	.8549
1.19	1.485	1.324	1.122	1.059	.9937	.8485
1.20	1.513	1.342	1.128	1.062	.9928	.8422
1.21	1.541	1.359	1.134	1.065	.9918	.8360
1.22	1.570	1.376	1.141	1.068	.9907	.8300
1.23	1.598	1.394	1.147	1.071	.9896	.8241
1.24	1.627	1.411	1.153	1.074	.9884	.8183
1.25	1.656	1.429	1.159	1.077	.9871	.8126
1.26	1.686	1.446	1.166	1.080	.9857	.8071
1.27	1.715	1.463	1.172	1.083	.9842	.8016
1.28	1.745	1.481	1.178	1.085	.9827	.7963
1.29	1.775	1.498	1.185	1.088	.9811	.7911
1.30	1.805	1.516	1.191	1.091	.9794	.7860
1.31	1.835	1.533	1.197	1.094	.9776	.7809
1.32	1.866	1.551	1.204	1.097	.9758	.7760
1.33	1.897	1.568	1.210	1.100	.9738	.7712
1.34	1.928	1.585	1.216	1.103	.9718	.7664
1.35	1.960	1.603	1.223	1.106	.9697	.7618
1.36	1.991	1.620	1.229	1.109	.9676	.7572
1.37	2.023	1.638	1.235	1.111	.9653	.7527
1.38	2.055	1.655	1.242	1.114	.9630	.7483
1.39	2.087	1.672	1.248	1.117	.9606	.7440
1.40	2.120	1.690	1.255	1.120	.9582	.7397
1.41	2.153	1.707	1.261	1.123	.9557	.7355
1.42	2.186	1.724	1.268	1.126	.9531	.7314
1.43	2.219	1.742	1.274	1.129	.9504	.7274
1.44	2.253	1.759	1.281	1.132	.9476	.7235
1.45	2.286	1.776	1.287	1.135	.9448	.7196
1.46	2.320	1.793	1.294	1.137	.9420	.7157
1.47	2.354	1.811	1.300	1.140	.9390	.7120
1.48	2.389	1.828	1.307	1.143	.9360	.7083
1.49	2.423	1.845	1.314	1.146	.9329	.7047
1.50	2.458	1.862	1.320	1.149	.9298	.7011
1.51	2.493	1.879	1.327	1.152	.9266	.6976
1.52	2.529	1.896	1.334	1.155	.9233	.6941
1.53	2.564	1.913	1.340	1.158	.9200	.6907
1.54	2.600	1.930	1.347	1.161	.9166	.6874
1.55	2.636	1.947	1.354	1.164	.9132	.6841
1.56	2.673	1.964	1.361	1.166	.9097	.6809
1.57	2.709	1.981	1.367	1.169	.9061	.6777
1.58	2.746	1.998	1.374	1.172	.9026	.6746
1.59	2.783	2.015	1.381	1.175	.8989	.6715
1.60	2.820	2.032	1.388	1.178	.8952	.6684
1.61	2.857	2.049	1.395	1.181	.8914	.6655
1.62	2.895	2.065	1.402	1.184	.8877	.6625
1.63	2.933	2.082	1.409	1.187	.8838	.6596
1.64	2.971	2.099	1.416	1.190	.8799	.6568
1.65	3.010	2.115	1.423	1.193	.8760	.6540
1.66	3.048	2.132	1.430	1.196	.8720	.6512
1.67	3.087	2.148	1.437	1.199	.8680	.6485
1.68	3.126	2.165	1.444	1.202	.8640	.6458
1.69	3.165	2.181	1.451	1.205	.8599	.6431
1.70	3.205	2.198	1.458	1.208	.8557	.6405
1.71	3.245	2.214	1.466	1.211	.8516	.6380
1.72	3.285	2.230	1.473	1.214	.8474	.6355
1.73	3.325	2.247	1.480	1.217	.8431	.6330
1.74	3.366	2.263	1.487	1.220	.8389	.6305
1.75	3.406	2.279	1.495	1.223	.8346	.6281
1.76	3.447	2.295	1.502	1.226	.8302	.6257
1.77	3.488	2.311	1.509	1.229	.8259	.6234
1.78	3.530	2.327	1.517	1.232	.8215	.6210
1.79	3.571	2.343	1.524	1.235	.8171	.6188
1.80	3.613	2.359	1.532	1.238	.8127	.6165
1.81	3.655	2.375	1.539	1.241	.8082	.6143
1.82	3.698	2.391	1.547	1.244	.8038	.6121
1.83	3.740	2.407	1.554	1.247	.7993	.6099
1.84	3.783	2.422	1.562	1.250	.7948	.6078
1.85	3.826	2.438	1.569	1.253	.7902	.6057
1.86	3.870	2.454	1.577	1.256	.7857	.6036
1.87	3.913	2.469	1.585	1.259	.7811	.6016
1.88	3.957	2.485	1.592	1.262	.7765	.5996
1.89	4.001	2.500	1.600	1.265	.7720	.5976
1.90	4.045	2.516	1.608	1.268	.7674	.5956
1.91	4.089	2.531	1.616	1.271	.7627	.5937
1.92	4.134	2.546	1.624	1.274	.7581	.5918
1.93	4.179	2.562	1.631	1.277	.7535	.5899
1.94	4.224	2.577	1.639	1.280	.7488	.5880
1.95	4.270	2.592	1.647	1.283	.7442	.5862
1.96	4.315	2.607	1.655	1.287	.7395	.5844
1.97	4.361	2.622	1.663	1.290	.7349	.5826
1.98	4.407	2.637	1.671	1.293	.7302	.5808
1.99	4.453	2.652	1.679	1.296	.7255	.5791
2.00	4.500	2.667	1.688	1.299	.7209	.5774
2.01	4.547	2.681	1.696	1.302	.7162	.5757
2.02	4.594	2.696	1.704	1.305	.7115	.5740
2.03	4.641	2.711	1.712	1.308	.7069	.5723
2.04	4.689	2.725	1.720	1.312	.7022	.5707
2.05	4.736	2.740	1.729	1.315	.6975	.5691
2.06	4.784	2.755	1.737	1.318	.6928	.5675
2.07	4.832	2.769	1.745	1.321	.6882	.5659
2.08	4.881	2.783	1.754	1.324	.6835	.5643
2.09	4.929	2.798	1.762	1.327	.6789	.5628
2.10	4.978	2.812	1.770	1.331	.6742	.5613
2.11	5.027	2.826	1.779	1.334	.6696	.5598
2.12	5.077	2.840	1.787	1.337	.6649	.5583
2.13	5.126	2.854	1.796	1.340	.6603	.5568
2.14	5.176	2.868	1.805	1.343	.6557	.5554
2.15	5.226	2.882	1.813	1.347	.6511	.5540
2.16	5.277	2.896	1.822	1.350	.6464	.5525
2.17	5.327	2.910	1.831	1.353	.6419	.5511
2.18	5.378	2.924	1.839	1.356	.6373	.5498
2.19	5.429	2.938	1.848	1.359	.6327	.5484
2.20	5.480	2.951	1.857	1.363	.6281	.5471
2.21	5.531	2.965	1.866	1.366	.6236	.5457
2.22	5.583	2.978	1.875	1.369	.6191	.5444
2.23	5.635	2.992	1.883	1.372	.6145	.5431
2.24	5.687	3.005	1.892	1.376	.6100	.5418
2.25	5.740	3.019	1.901	1.379	.6055	.5406
2.26	5.792	3.032	1.910	1.382	.6011	.5393
2.27	5.845	3.045	1.919	1.385	.5966	.5381
2.28	5.898	3.058	1.929	1.389	.5921	.5368
2.29	5.951	3.071	1.938	1.392	.5877	.5356
2.30	6.005	3.085	1.947	1.395	.5833	.5344
2.31	6.059	3.098	1.956	1.399	.5789	.5332
2.32	6.113	3.110	1.965	1.402	.5745	.5321
2.33	6.167	3.123	1.974	1.405	.5702	.5309
2.34	6.222	3.136	1.984	1.408	.5658	.5297
2.35	6.276	3.149	1.993	1.412	.5615	.5286
2.36	6.331	3.162	2.002	1.415	.5572	.5275
2.37	6.386	3.174	2.012	1.418	.5529	.5264
2.38	6.442	3.187	2.021	1.422	.5486	.5253
2.39	6.497	3.199	2.031	1.425	.5444	.5242

(Isentropic Flow Charts on Other Side)

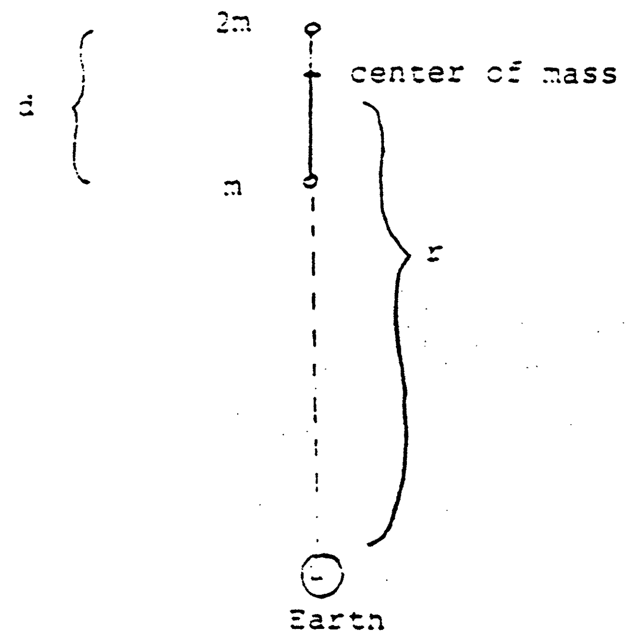
Problem 9, table continued

Parameters for ID Isentropic Supersonic Flow

M	$\frac{p}{p_0}$	$\frac{\rho}{\rho_0}$	$\frac{T}{T_0}$	$\frac{a}{a_0}$	$\frac{A^*}{A}$	$\frac{\frac{\rho}{2}V^2}{p_0}$	ν
1.00	.5283	.6339	.8333	.9129	1.0000	.3698	0
1.01	.5221	.6287	.8306	.9113	.9999	.3728	.04473
1.02	.5160	.6234	.8278	.9098	.9997	.3758	.1257
1.03	.5099	.6181	.8250	.9083	.9993	.3787	.2294
1.04	.5039	.6129	.8222	.9067	.9987	.3815	.3510
1.05	.4979	.6077	.8193	.9052	.9980	.3842	.4874
1.06	.4919	.6024	.8165	.9036	.9971	.3869	.6367
1.07	.4860	.5972	.8137	.9020	.9961	.3895	.7973
1.08	.4800	.5920	.8108	.9005	.9949	.3919	.9680
1.09	.4742	.5869	.8080	.8989	.9936	.3944	1.148
1.10	.4684	.5817	.8052	.8973	.9921	.3967	1.336
1.11	.4626	.5766	.8023	.8957	.9906	.3990	1.532
1.12	.4568	.5714	.7994	.8941	.9888	.4011	1.735
1.13	.4511	.5663	.7966	.8925	.9870	.4032	1.944
1.14	.4455	.5612	.7937	.8909	.9850	.4052	2.160
1.15	.4398	.5562	.7908	.8893	.9828	.4072	2.381
1.16	.4343	.5511	.7879	.8877	.9806	.4090	2.607
1.17	.4287	.5461	.7851	.8860	.9782	.4108	2.839
1.18	.4232	.5411	.7822	.8844	.9758	.4125	3.074
1.19	.4178	.5361	.7793	.8828	.9732	.4141	3.314
1.20	.4124	.5311	.7764	.8811	.9705	.4157	3.558
1.21	.4070	.5262	.7735	.8795	.9676	.4171	3.806
1.22	.4017	.5213	.7706	.8778	.9647	.4185	4.057
1.23	.3964	.5164	.7677	.8762	.9617	.4198	4.312
1.24	.3912	.5115	.7648	.8745	.9586	.4211	4.569
1.25	.3861	.5067	.7619	.8729	.9553	.4223	4.830
1.26	.3809	.5019	.7590	.8712	.9520	.4233	5.093
1.27	.3759	.4971	.7561	.8695	.9486	.4244	5.359
1.28	.3708	.4923	.7532	.8679	.9451	.4253	5.627
1.29	.3658	.4876	.7503	.8662	.9415	.4262	5.898
1.30	.3609	.4829	.7474	.8645	.9378	.4270	6.170
1.31	.3560	.4782	.7445	.8628	.9341	.4277	6.445
1.32	.3512	.4736	.7416	.8611	.9302	.4283	6.721
1.33	.3464	.4690	.7387	.8595	.9263	.4289	7.000
1.34	.3417	.4644	.7358	.8578	.9223	.4294	7.279
1.35	.3370	.4598	.7329	.8561	.9182	.4299	7.561
1.36	.3323	.4553	.7300	.8544	.9141	.4303	7.844
1.37	.3277	.4508	.7271	.8527	.9099	.4306	8.128
1.38	.3232	.4463	.7242	.8510	.9056	.4308	8.413
1.39	.3187	.4418	.7213	.8493	.9013	.4310	8.699
1.40	.3142	.4374	.7184	.8476	.8969	.4311	8.987
1.41	.3098	.4330	.7155	.8459	.8925	.4312	9.276
1.42	.3055	.4287	.7126	.8442	.8880	.4312	9.565
1.43	.3012	.4244	.7097	.8425	.8834	.4311	9.855
1.44	.2969	.4201	.7069	.8407	.8788	.4310	10.15
1.45	.2927	.4158	.7040	.8390	.8742	.4308	10.44
1.46	.2886	.4116	.7011	.8373	.8695	.4306	10.73
1.47	.2845	.4074	.6982	.8356	.8647	.4303	11.02
1.48	.2804	.4032	.6954	.8339	.8599	.4299	11.32
1.49	.2764	.3991	.6925	.8322	.8551	.4295	11.61
1.50	.2724	.3950	.6897	.8305	.8502	.4290	11.91
1.51	.2685	.3909	.6868	.8287	.8453	.4285	12.20
1.52	.2646	.3869	.6840	.8270	.8404	.4279	12.49
1.53	.2608	.3829	.6811	.8253	.8354	.4273	12.79
1.54	.2570	.3789	.6783	.8236	.8304	.4266	13.09
1.55	.2533	.3750	.6754	.8219	.8254	.4259	13.38
1.56	.2496	.3710	.6726	.8201	.8203	.4252	13.68
1.57	.2459	.3672	.6698	.8184	.8152	.4243	13.97
1.58	.2423	.3633	.6670	.8167	.8101	.4235	14.27
1.59	.2388	.3596	.6642	.8150	.8050	.4226	14.56
1.60	.2353	.3557	.6614	.8133	.7998	.4216	14.86
1.61	.2318	.3520	.6586	.8115	.7947	.4206	15.16
1.62	.2284	.3483	.6558	.8098	.7895	.4196	15.45
1.63	.2250	.3446	.6530	.8081	.7843	.4185	15.75
1.64	.2217	.3409	.6502	.8064	.7791	.4174	16.04
1.65	.2184	.3373	.6475	.8046	.7739	.4162	16.34
1.66	.2151	.3337	.6447	.8029	.7686	.4150	16.63
1.67	.2119	.3302	.6419	.8012	.7634	.4138	16.93
1.68	.2088	.3266	.6392	.7995	.7581	.4125	17.22
1.69	.2057	.3232	.6364	.7978	.7529	.4112	17.52
1.70	.2026	.3197	.6337	.7961	.7476	.4098	17.81
1.71	.1996	.3163	.6310	.7943	.7423	.4086	18.10
1.72	.1966	.3129	.6283	.7926	.7371	.4071	18.40
1.73	.1936	.3095	.6256	.7909	.7318	.4056	18.69
1.74	.1907	.3062	.6229	.7892	.7265	.4041	18.98
1.75	.1878	.3029	.6202	.7875	.7212	.4026	19.27
1.76	.1850	.2996	.6175	.7858	.7160	.4011	19.56
1.77	.1822	.2964	.6148	.7841	.7107	.3996	19.86
1.78	.1794	.2932	.6121	.7824	.7054	.3980	20.15
1.79	.1767	.2900	.6095	.7807	.7002	.3964	20.44
1.80	.1740	.2868	.6068	.7790	.6949	.3947	20.73
1.81	.1714	.2837	.6041	.7773	.6897	.3931	21.01
1.82	.1688	.2806	.6015	.7756	.6845	.3914	21.30
1.83	.1662	.2776	.5989	.7739	.6792	.3897	21.59
1.84	.1637	.2745	.5963	.7722	.6740	.3879	21.88
1.85	.1612	.2715	.5936	.7705	.6688	.3862	22.16
1.86	.1587	.2686	.5910	.7688	.6636	.3844	22.45
1.87	.1563	.2656	.5884	.7671	.6584	.3826	22.73
1.88	.1539	.2627	.5859	.7654	.6533	.3808	23.02
1.89	.1516	.2598	.5833	.7637	.6481	.3790	23.30
1.90	.1492	.2570	.5807	.7620	.6430	.3771	23.59
1.91	.1470	.2542	.5782	.7604	.6379	.3753	23.87
1.92	.1447	.2514	.5756	.7587	.6328	.3734	24.15
1.93	.1425	.2486	.5731	.7570	.6277	.3715	24.43
1.94	.1403	.2459	.5706	.7553	.6226	.3696	24.71
1.95	.1381	.2432	.5680	.7537	.6175	.3677	24.99
1.96	.1360	.2405	.5655	.7520	.6125	.3657	25.27
1.97	.1339	.2378	.5630	.7503	.6075	.3638	25.55
1.98	.1318	.2352	.5605	.7487	.6025	.3618	25.83
1.99	.1298	.2326	.5580	.7470	.5975	.3598	26.10
2.00	.1278	.2300	.5556	.7454	.5926	.3579	26.38
2.01	.1258	.2275	.5531	.7437	.5877	.3559	26.66
2.02	.1239	.2250	.5506	.7420	.5828	.3539	26.93
2.03	.1220	.2225	.5482	.7404	.5779	.3518	27.20
2.04	.1201	.2200	.5458	.7388	.5730	.3498	27.48
2.05	.1182	.2176	.5433	.7371	.5682	.3478	27.75
2.06	.1164	.2152	.5409	.7355	.5634	.3458	28.02
2.07	.1146	.2128	.5385	.7338	.5586	.3437	28.29
2.08	.1128	.2104	.5361	.7322	.5538	.3417	28.56
2.09	.1111	.2081	.5337	.7306	.5491	.3396	28.83
2.10	.1094	.2058	.5313	.7289	.5444	.3376	29.10
2.11	.1077	.2035	.5290	.7273	.5397	.3355	29.36
2.12	.1060	.2013	.5266	.7257	.5350	.3334	29.63
2.13	.1043	.1990	.5243	.7241	.5304	.3314	29.90
2.14	.1027	.1968	.5219	.7225	.5258	.3293	30.16
2.15	.1011	.1946	.5196	.7208	.5212	.3272	30.43
2.16	.09956	.1925	.5173	.7192	.5167	.3252	30.69
2.17	.09802	.1903	.5150	.7176	.5122	.3231	30.95
2.18	.09650	.1882	.5127	.7160	.5077	.3210	31.21
2.19	.09500	.1861	.5104	.7144	.5032	.3189	31.47
2.20	.09352	.1841	.5081	.7128	.4988	.3169	31.73
2.21	.09207	.1820	.5059	.7112	.4944	.3148	31.99
2.22	.09064	.1800	.5036	.7097	.4900	.3127	32.25
2.23	.08923	.1780	.5014	.7081	.4856	.3106	32.51
2.24	.08785	.1760	.4991	.7065	.4813	.3085	32.76
2.25	.08648	.1740	.4969	.7049	.4770	.3065	33.02
2.26	.08514	.1721	.4947	.7033	.4727	.3044	33.27
2.27	.08382	.1702	.4925	.7018	.4685	.3023	33.53
2.28	.08252	.1683	.4903	.7002	.4643	.3003	33.78
2.29	.08123	.1664	.4881	.6986	.4601	.2982	34.03
2.30	.07997	.1646	.4859	.6971	.4560	.2961	34.28
2.31	.07873	.1628	.4837	.6955	.4519	.2941	34.53
2.32	.07751	.1609	.4816	.6940	.4478	.2920	34.78
2.33	.07631	.1592	.4794	.6924	.4437	.2900	35.03
2.34	.07512	.1574	.4773	.6909	.4397	.2879	35.28
2.35	.07396	.1556	.4752	.6893	.4357	.2859	35.53
2.36	.07281	.1539	.4731	.6878	.4317	.2839	35.77
2.37	.07168	.1522	.4710	.6863	.4278	.2818	36.02
2.38	.07057	.1505	.4688	.6847	.4239	.2798	36.26
2.39	.06948	.1488	.4668	.6832	.4200	.2778	36.50

(Normal Shock Charts on Other Side)

Question 10.



Two satellites of mass, m and 2m, are connected by a massless vertical tether of length, d. The center of mass of the two satellites is in circular orbit at distance, r, from the center of Earth which has gravitational parameter, μ.

For the center of mass and each separate mass write an expression in terms of m, r, d, μ for:

1.) velocity

2.) angular momentum

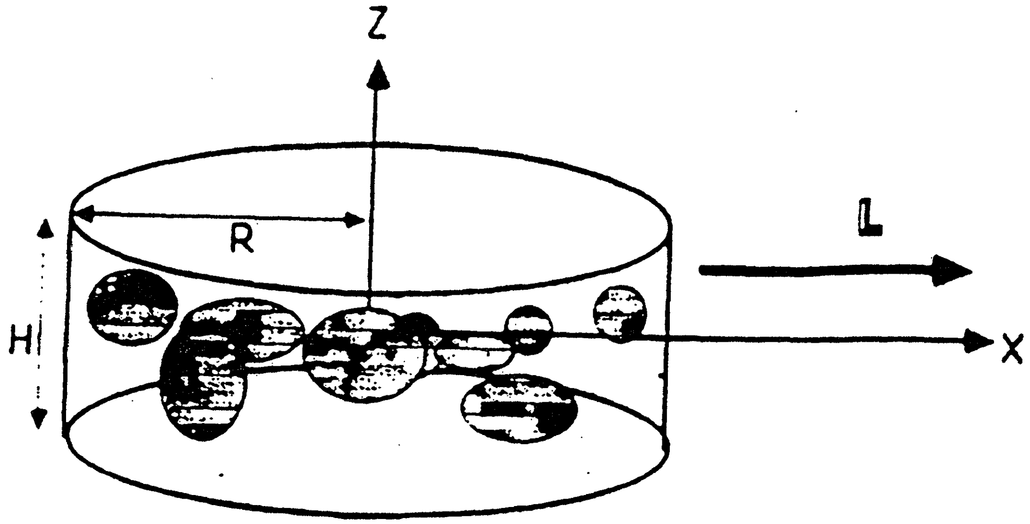
3.) kinetic energy

4.) potential energy

5.) total energy

Use your result to describe what you could expect to happen as the tether is wound in.

Question 11.



A 1/4 full, massless cylindrical fuel tank with a radius R twice the height H is freely floating in zero gravity with the fuel arbitrarily distributed throughout the tank. Due to a thruster malfunction, an angular momentum L is imparted to the system about the x axis. This torque also excites fuel slosh in the tank which results in energy dissipation. Using energy and conservation considerations, describe the state of the system after a very long time:

a.) Where will the fluid be located within the tank?

b.) What will be the final rotation rate?

c.) What will be the axis of rotation?

Explain your reasoning.

Question 12.

Assume that the density ρ of the atmosphere varies with altitude h according to the formula:

$$\rho = \rho_0 e^{-h/b}$$

where ρ_0 is the density at sea level (h=0), and b is some constant.

An airplane of mass M is flying through this atmosphere at a constant lift coefficient.

1.) If the airplane's speed at sea level is V_0, what is its speed as a function of altitude?

2.) Propulsive power is defined as (thrust) x (flight speed). If the airplane's lift-to-drag ratio is L/D, what is its level-flight propulsive power P_{LEVEL} as a function of altitude?

3.) The airplane starts at sea level (h=0) at time t=0, and flies at a constant propulsive power P. What is its altitude as a function of time? What is its ceiling at this power level?

Question 13.

Answer all five parts.

a.) For what value of k does the matrix equation

$$\begin{pmatrix} 1 & 2 & -2 \\ 0 & 1 & k \\ 8 & -3 & 4k \end{pmatrix} \vec{x} = \begin{pmatrix} 2 \\ 0 \\ 7 \end{pmatrix}$$

have no solution?

b.) Solve $\frac{d^2y}{dt^2} + 4y = 0$ subject to initial conditions $y(0) = 1$, $\frac{dy}{dt}(0) = 1$. Find y_{max}, the maximum value of $y(t)$, and the time(s) at which $y(t) = y_{max}$.

c.) Find a vector which is orthogonal to both

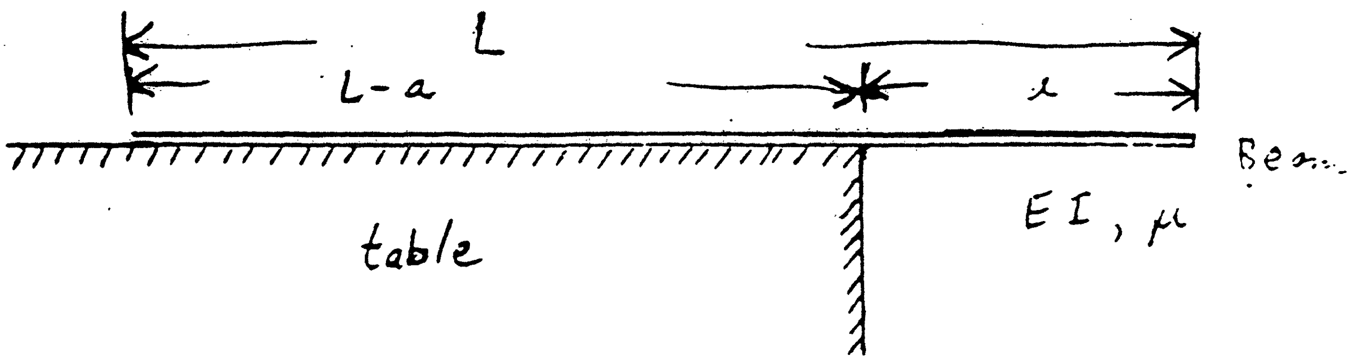
$$\begin{pmatrix} 1 \\ -4 \\ 2 \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} 3 \\ -2 \\ 1 \end{pmatrix}.$$

d.) Integrate $\int_0^\infty x^2 e^{-x}\, dx =$

e.) Find the first 5 terms of the Taylor series expansion of $f(x) = \cos[x(1-x)]$ about $x = 0$.

Question 14.

A uniform slender beam of length L, with bending stiffness EI and weight per unit length "μ" rests on a rigid horizontal table. A small portion of the beam, length a, $a = \frac{1}{3}L$, extends past the table's edge.



Assume:
- the table is rigid
- no friction between the beam and the beam, except sufficient friction at the corner to keep the beam on the table
- infinitesimal deflections

a.) Sketch the deflection curve of the beam.

b.) What is the force distribution between the beam and the table surface?

c.) What effects not modelled here might be important and how might they change the solution?

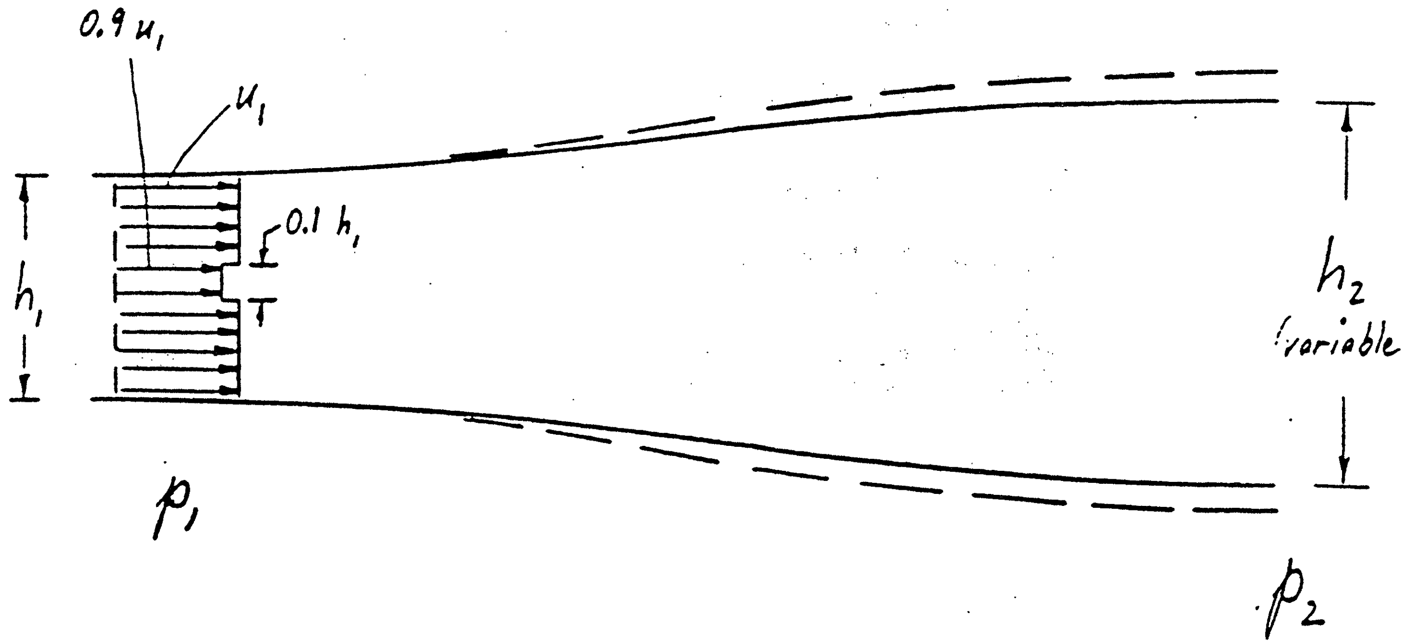
Question 15.

An incompressible, inviscid flow with density ρ is introduced into a diffuser having an adjustable exit height h_2. The inlet flow has a 90% low velocity region which covers 10% of the inlet cross-sectional area (see sketch).

1.) What is the maximum pressure rise (p_2-p_1) which can be obtained from this diffuser?

2.) What is the corresponding exit height h_2?

3.) Sketch the exit velocity profile for this case.

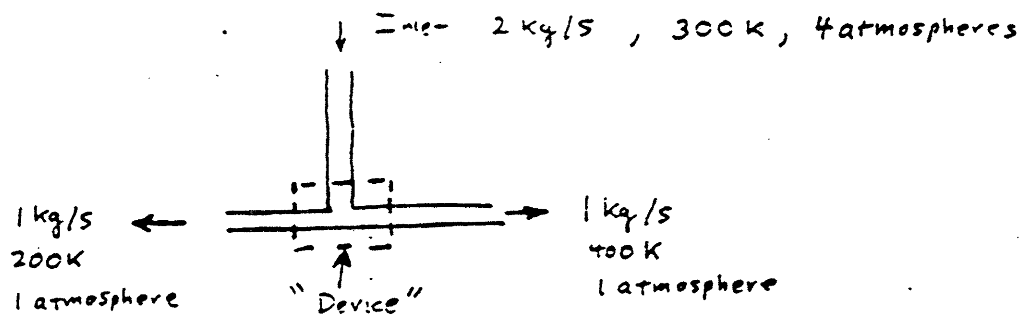


Question 17.

An inventor claims to have a flow device which takes 2 kg/s air at room temperature, say 300k, at a pressure of four atmospheres ($\sim 4\times10^5$ N/m^2) and yields 1 kg/s of air at atmosphere pressure at 400 k and one kg/s of air at atmosphere pressure and 200k.

a.) Is this possible?

b.) Why or why not?



Question 18.

The force exerted on a charge q by an "electric field" which is measured by observer (1) to be $\vec{E}$ is $q\vec{E}$. The force due to a magnetic field $\vec{B}$ is $q\vec{v} \times \vec{B}$, where $\vec{v}$ is the particle velocity as seen by the same observer (1). For non-relativistic speeds, $\vec{B}$ is independent of the motion of the reference frame; so is q in all cases. What is the electric field as seen by an observer (2) moving at velocity $\vec{V}$ with respect to the observer (1)?

Question 18.

The cylinder shown in the sketch has a velocity of 8,000 m/s; it is orbiting where the molecular number density is $n = 8.33 \times 10^{15}/m^3$, the ambient gas is predominantly O and the ambient temperature is 855K. The cylinder requires 150 watts/m^2 of power to overcome deceleration due to drag. Assuming equal values for normal (σ) and tangential (τ) accommodation coefficients estimate:

a) The fraction of the power that is used to overcome tangential drag.

b) The value of τ.

c) The drag coefficient on the frontal surface.

d) The net kinetic energy transferred per second to the frontal surface.