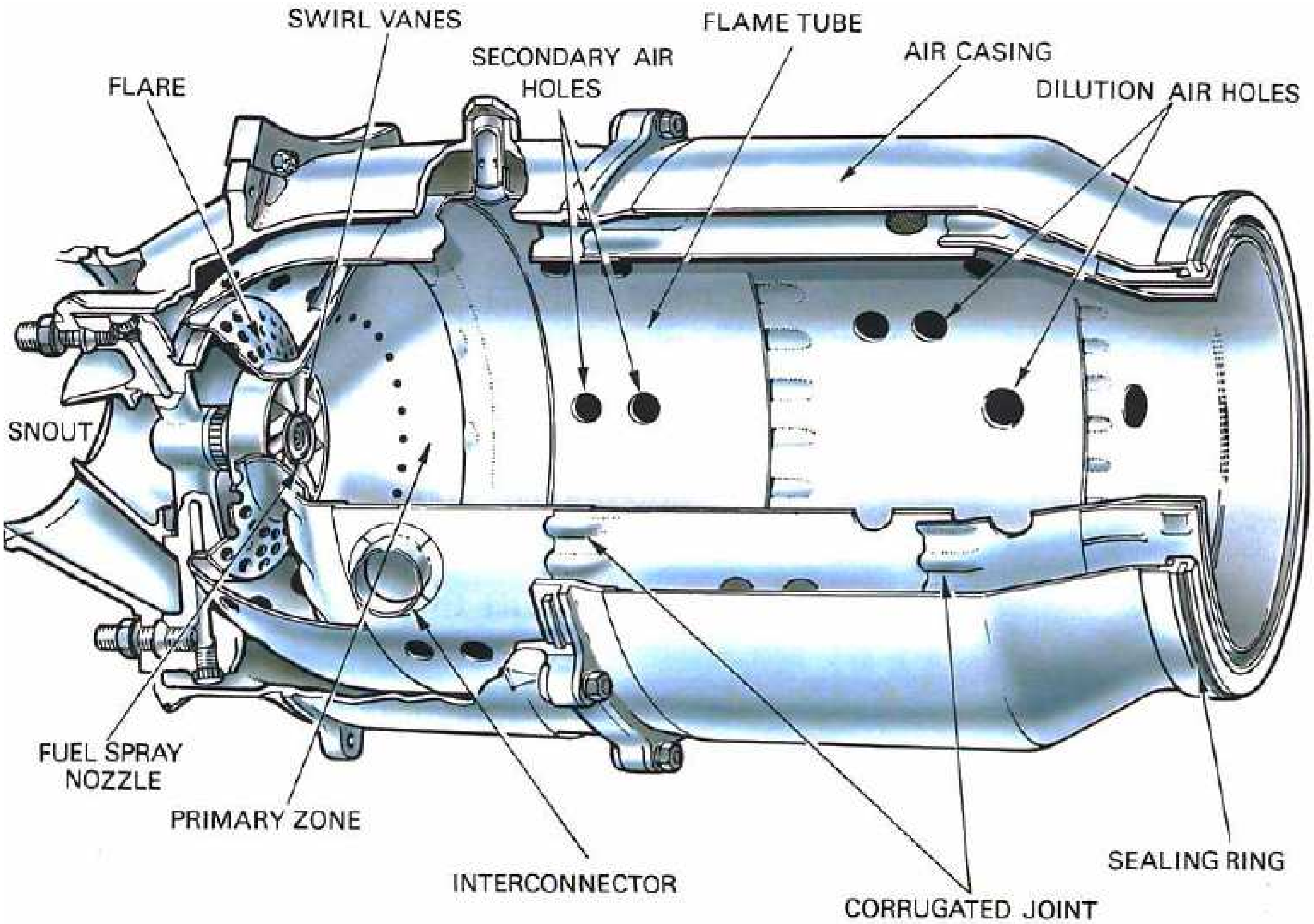
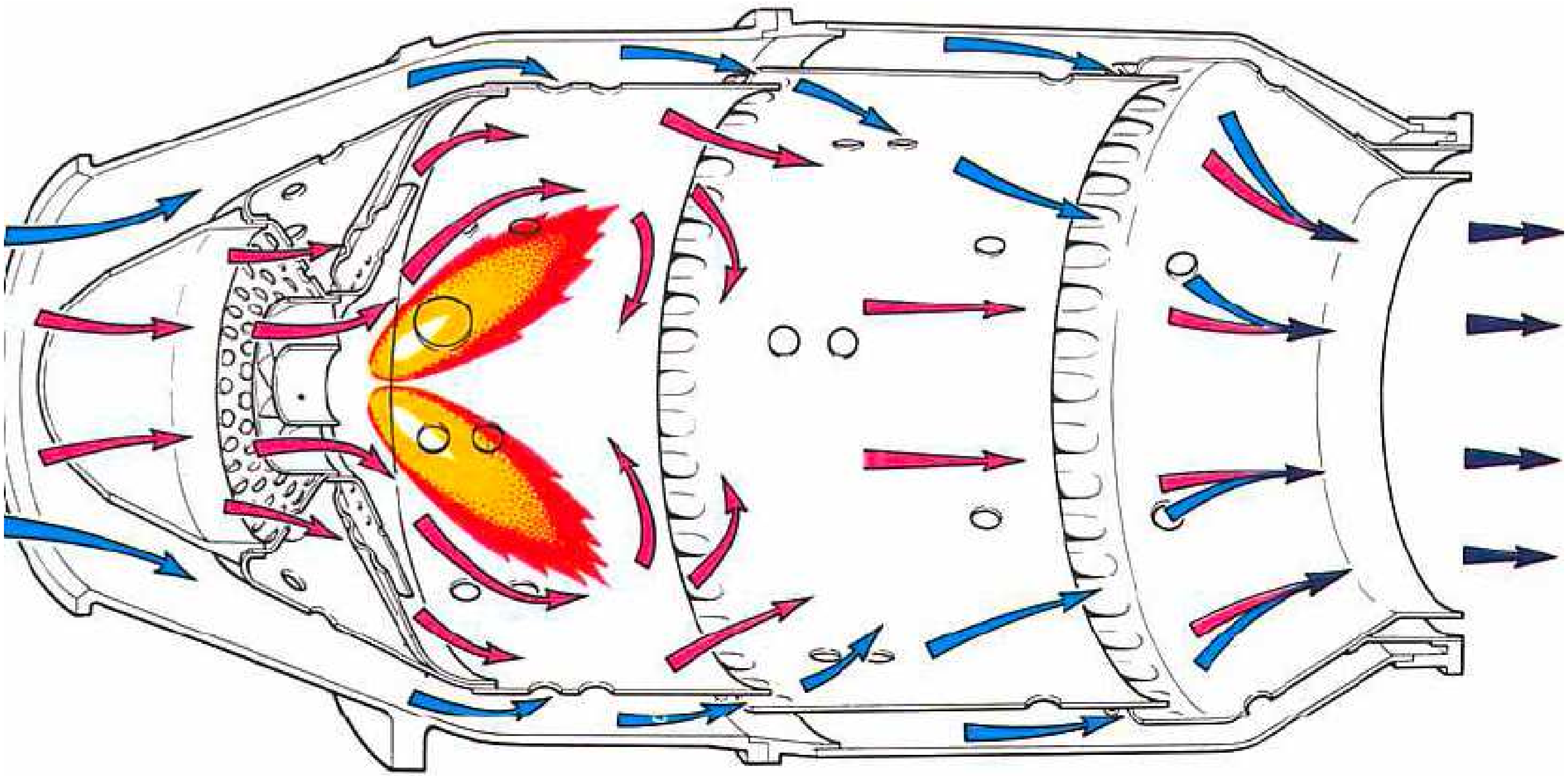
Turbinas a gás: Análise dos componentes

Parte 2

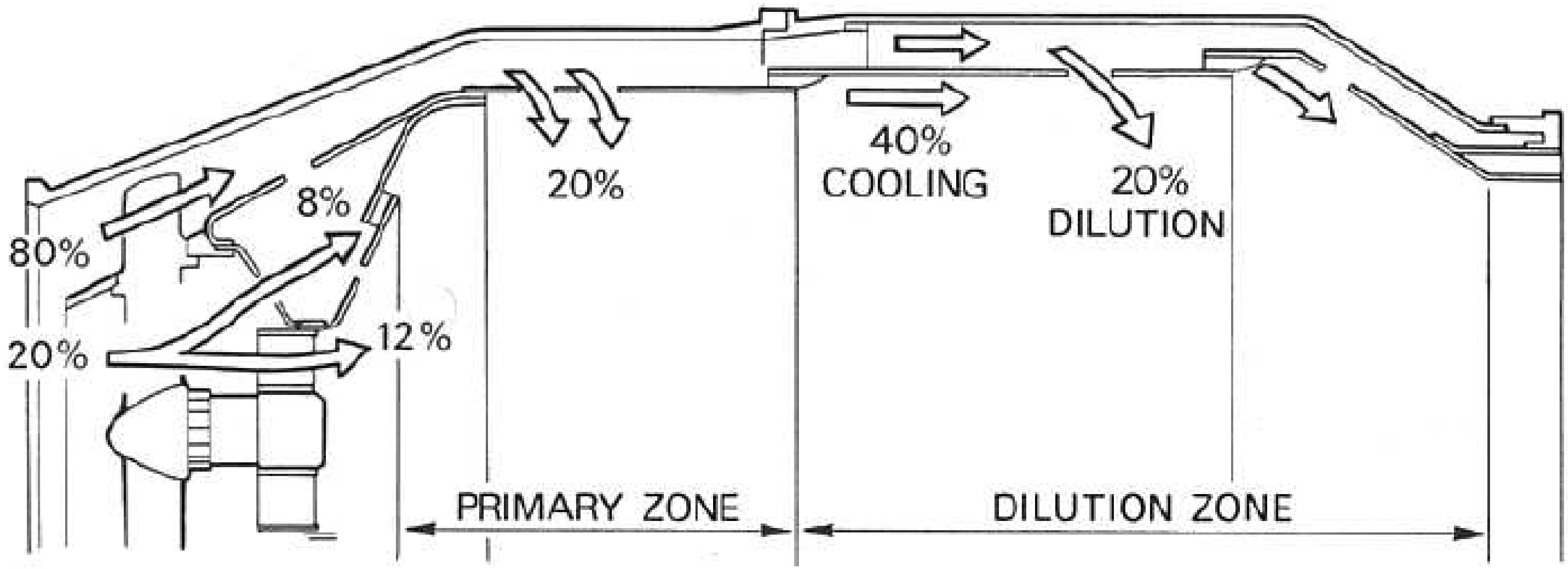
Câmara de combustão

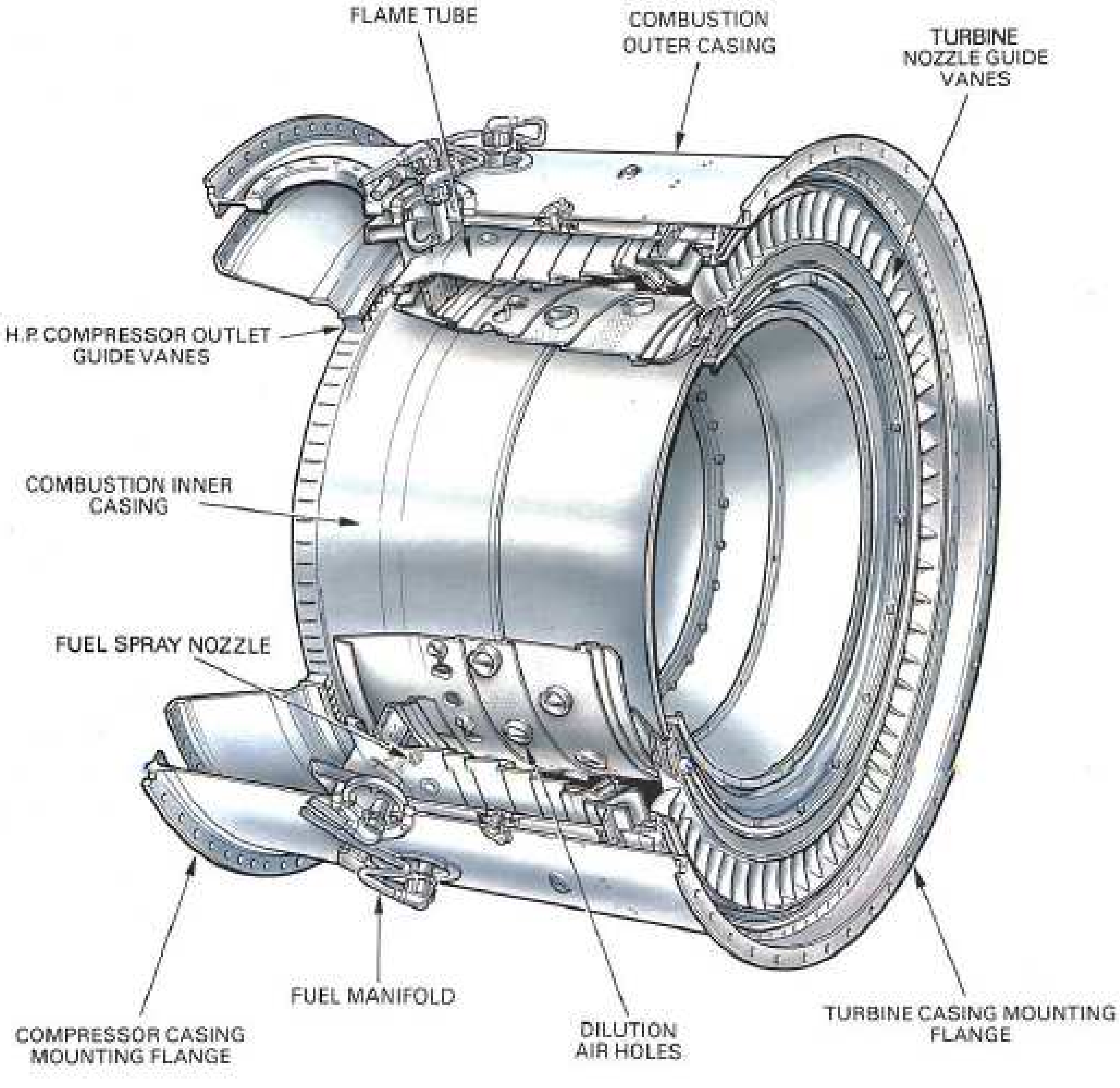


Câmara de combustão



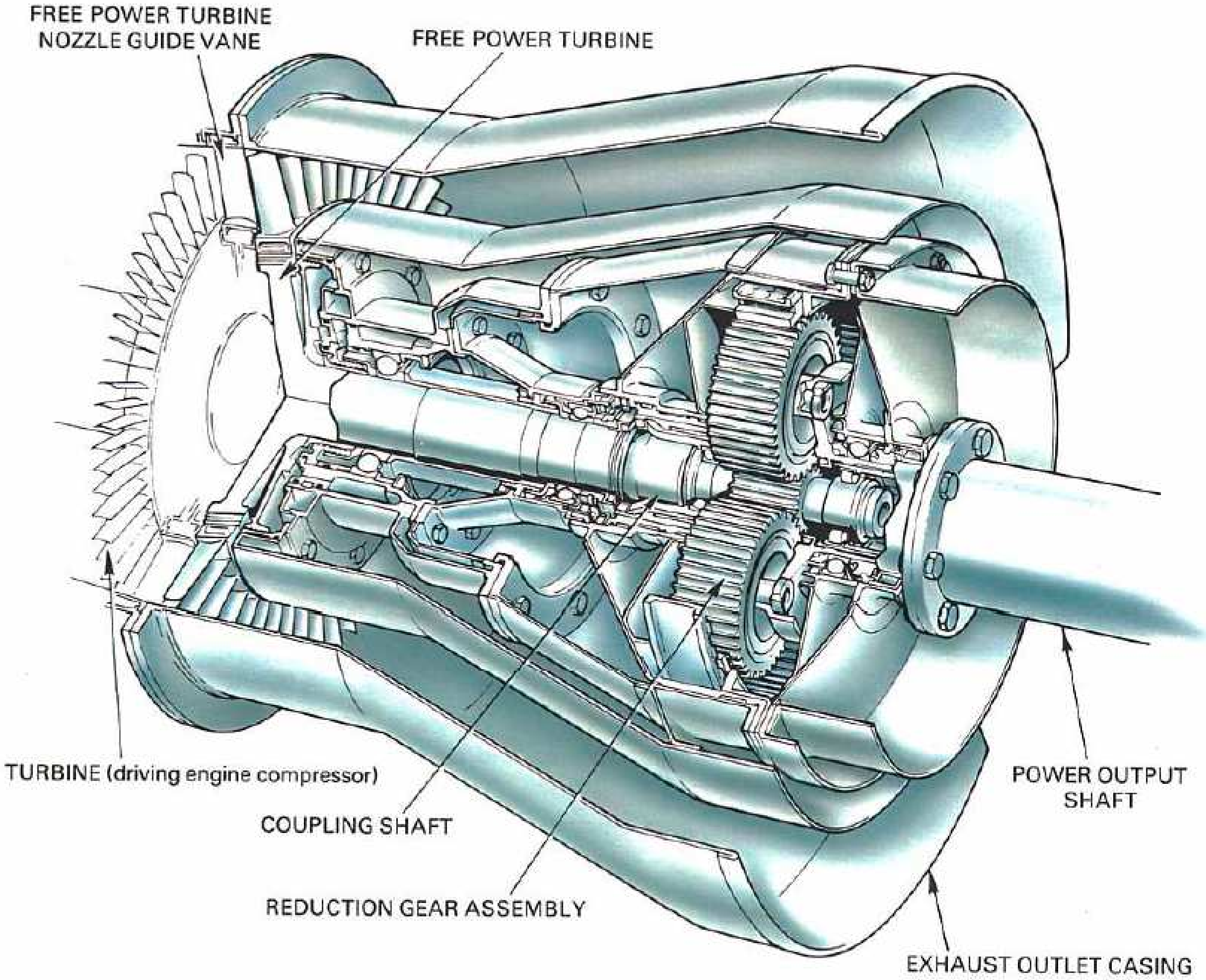
Câmara de combustão

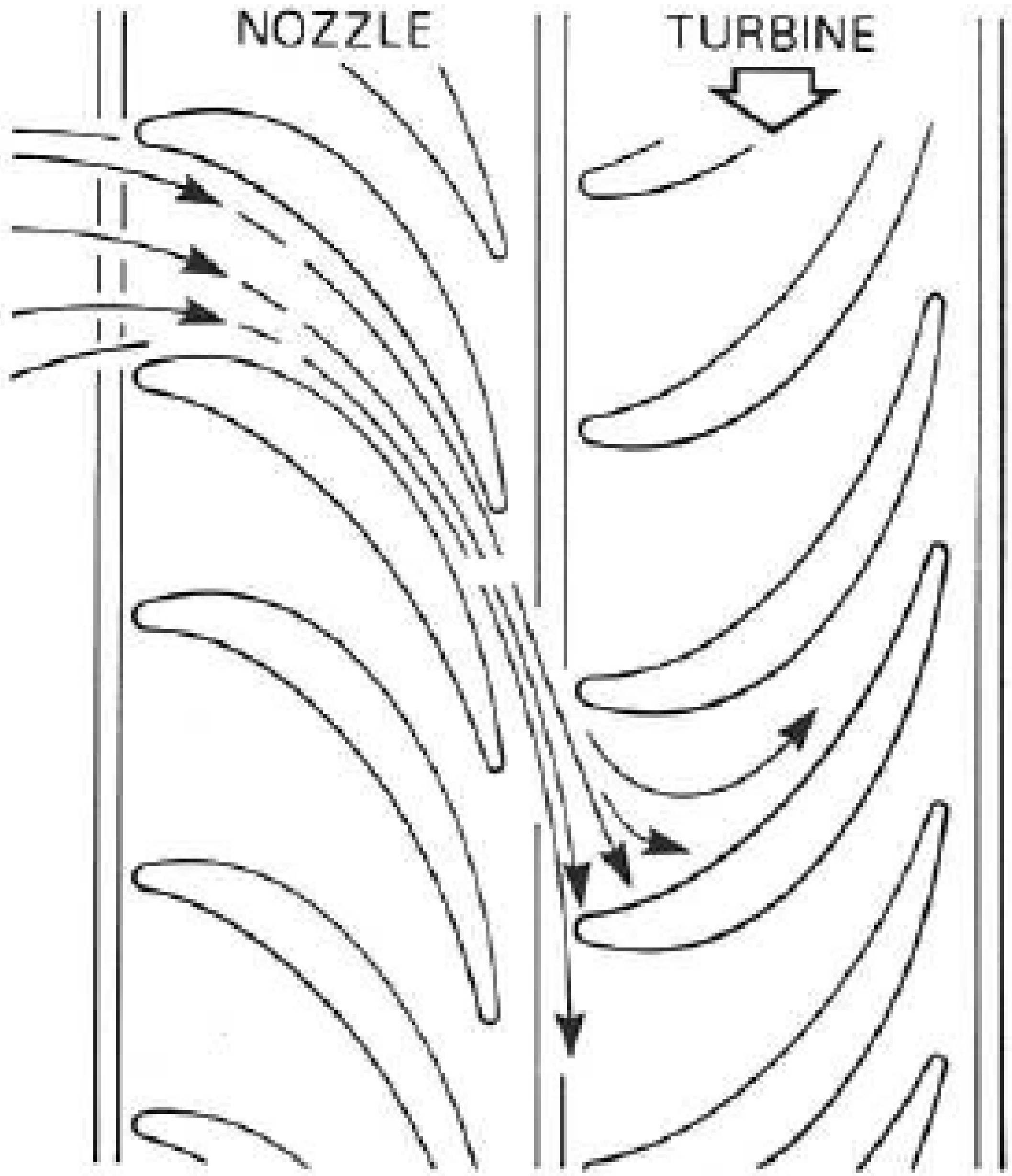


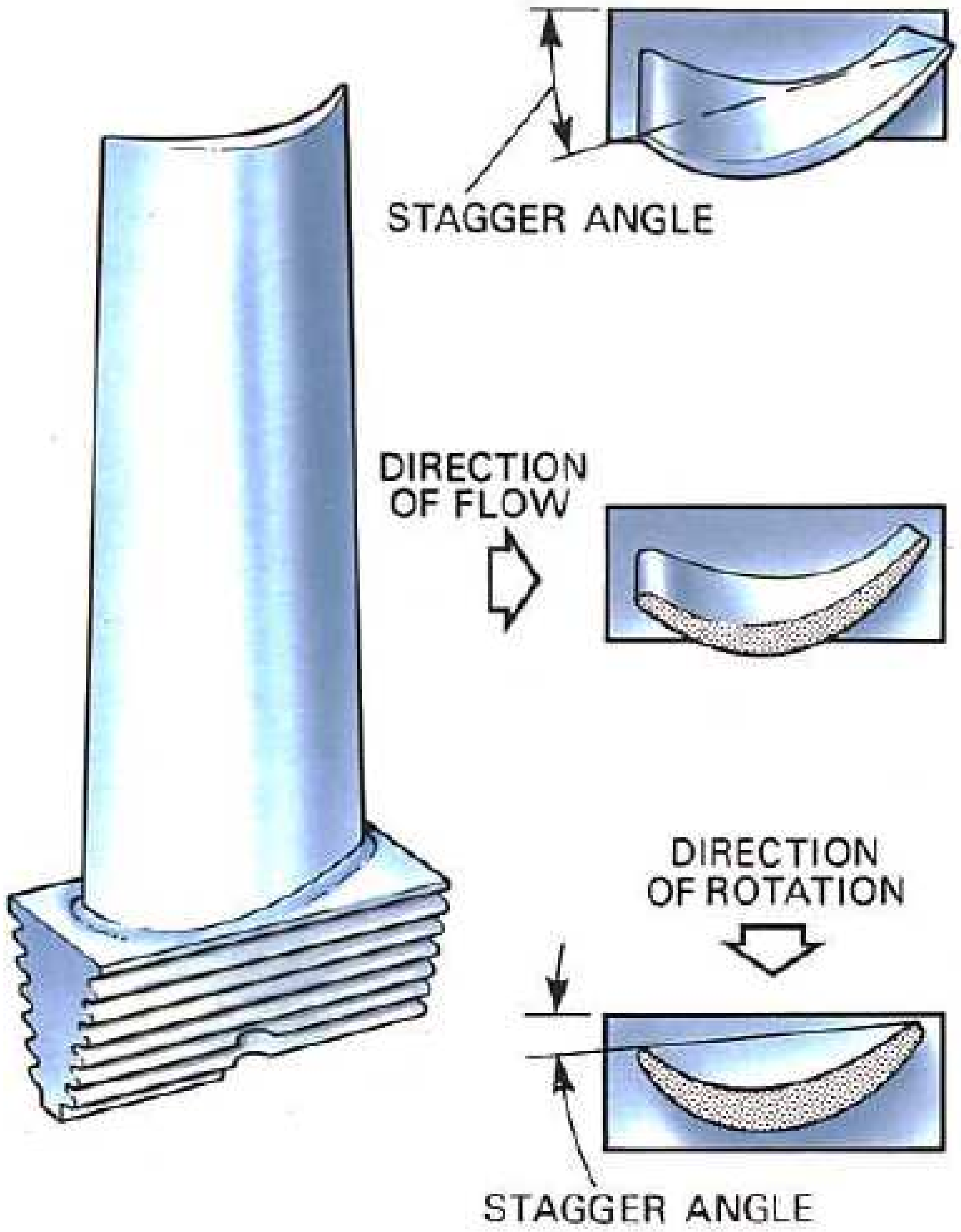

FLAME TUBE
COMBUSTION OUTER CASING
TURBINE NOZZLE GUIDE VANES
H.P. COMPRESSOR OUTLET GUIDE VANES
COMBUSTION INNER CASING
FUEL SPRAY NOZZLE
FUEL MANIFOLD
COMPRESSOR CASING MOUNTING FLANGE
DILUTION AIR HOLES
TURBINE CASING MOUNTING FLANGE

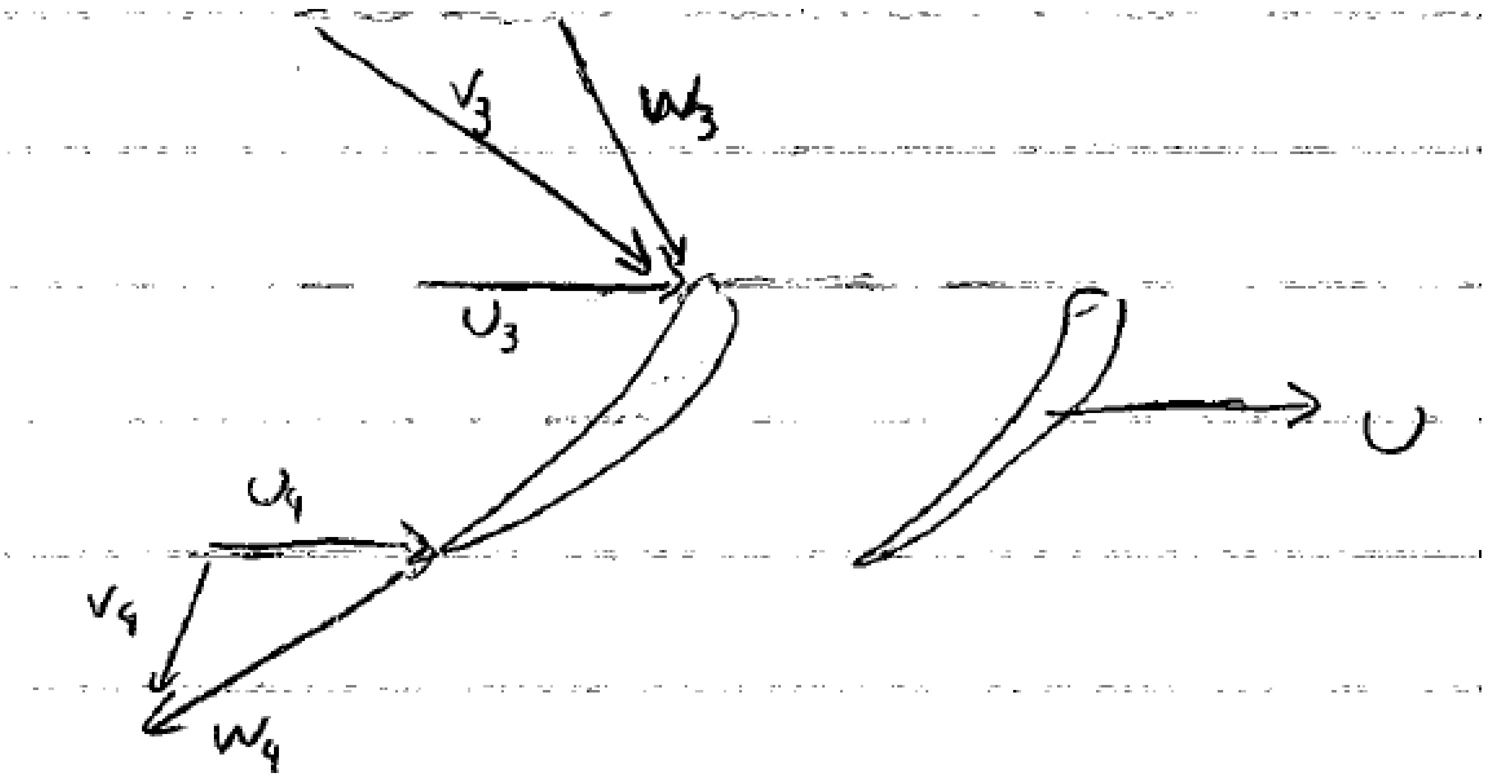
Exemplo

- Calcule a relação ar-combustível necessária para que, em uma câmara de combustão que recebe ar comprimido a 400K, a temperatura seja elevada de 750K. O combustível entra na câmara de combustão a 288K. O poder calorífico inferior do combustível é de 43MJ/kg. Adotar os calores específicos do ar e dos gases quentes como sendo 1005 e 1150 J/kgK, respectivamente. Considere que a eficiência da câmara de combustão é de 100%.

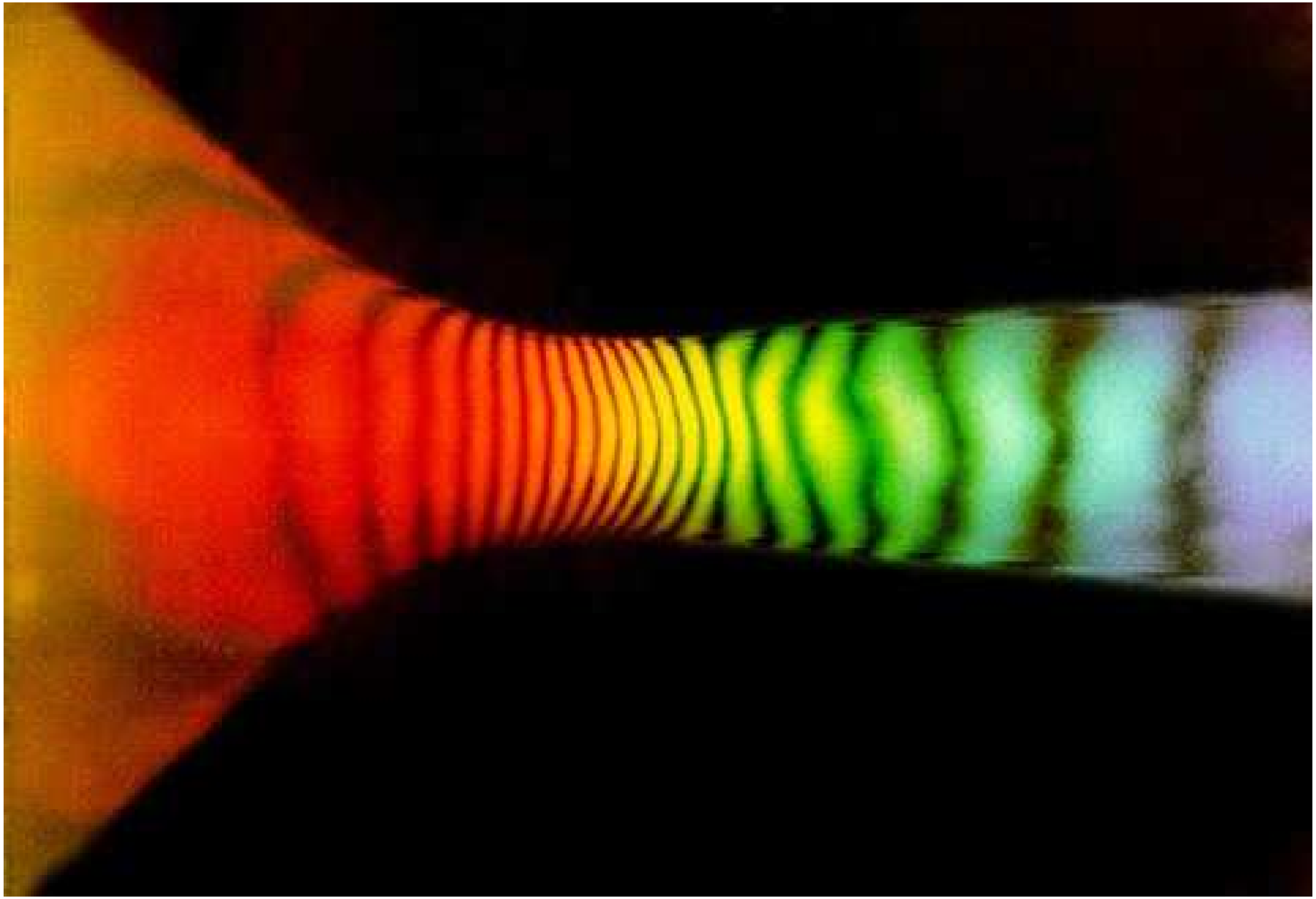

FREE POWER TURBINE
NOZZLE GUIDE VANE
FREE POWER TURBINE
TURBINE (driving engine compressor)
COUPLING SHAFT
REDUCTION GEAR ASSEMBLY
POWER OUTPUT
SHAFT
EXHAUST OUTLET CASING


NOZZLE
TURBINE

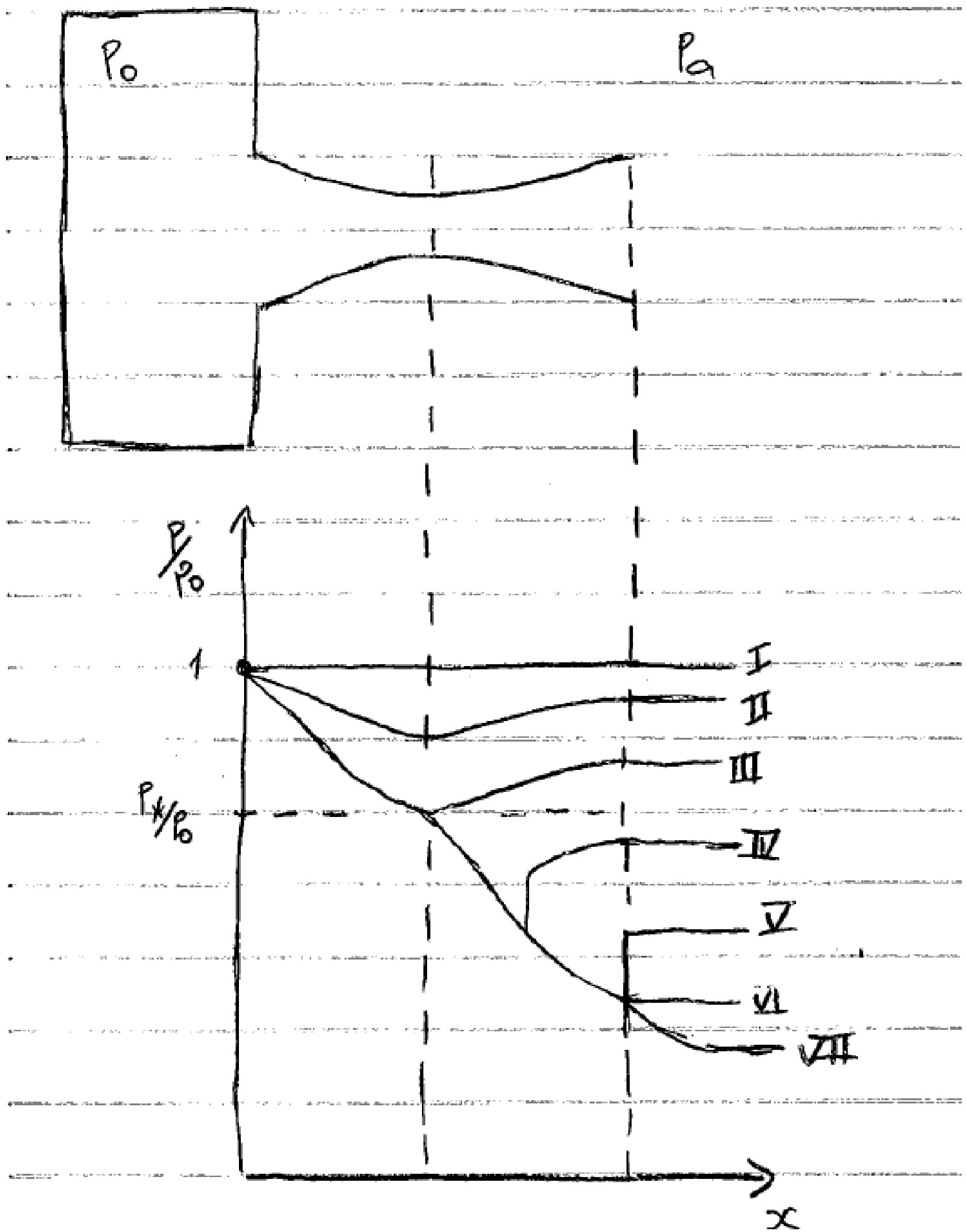

STAGGER ANGLE
DIRECTION
OF FLOW
DIRECTION
OF ROTATION
STAGGER ANGLE



V3
W3
U3
U
U4
V4
W4



Holographic interferogram of high-speed flow through a Laval nozzle. Image made at the Penn State Gas dynamics Laboratory.
http://www.me.psu.edu/psgdl/
http://media.efluids.com/galleries/compressible?medium=553


p_0
p_a
p/p_0
1
p_*/p_0
I
II
III
IV
V
VI
VII
x

Continuando com relações para compress.:

- Definição:
- $M_* = \frac{V}{a_*} = \frac{V}{V_*}$
- Mais algumas relações isentrópicas:
- $M_* = \frac{\frac{\gamma+1}{2}M^2}{1+\frac{\gamma-1}{2}M^2}$
- $\frac{A_*}{A} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{-1/\gamma-1}\left(\frac{2}{\gamma+1}\right)^{-1/\gamma-1}\left(\frac{\frac{\gamma+1}{2}M^2}{1+\frac{\gamma-1}{2}M^2}\right)^{1/2}$

Logo, para o bocal conv/div

- Se $P_{III} < P_s < P_{VI}$
  - Ondas de choque no interior do bocal.
- Como visto anteriormente:
  - Conhecidas cond. Antes do choque => cond. Depois do choque
- No choque (não é isentrópico!):
  - $M_{*1} = M_{*2}$
  - $a_{*1} = a_{*2}$
  - $T_{*1} = T_{*2}$
  - $T_{t1} = T_{t2}$

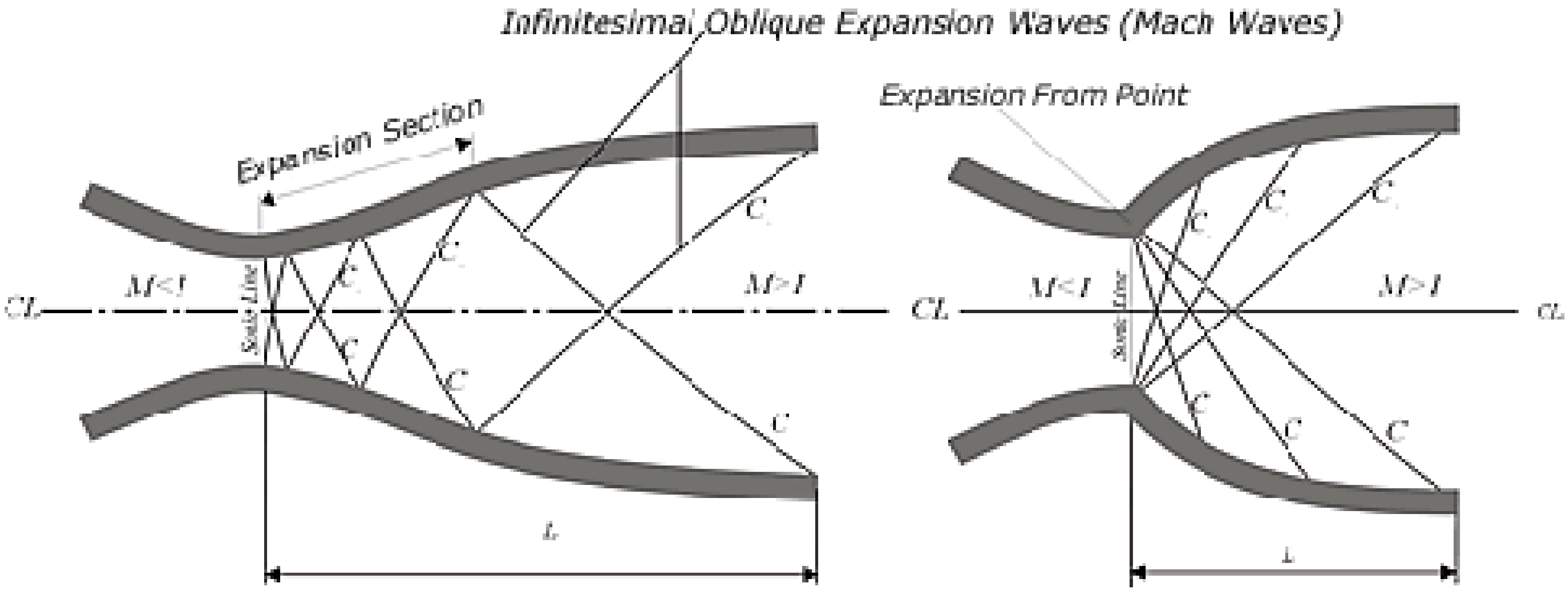
M	T/t	P/p	V/root(T)	m root(T)/AP	m root(T)/Ap	A/A*
1,950	1,7605	7,2398	29,4592	0,0250	0,1807	1,6193
1,955	1,7644	7,2962	29,5021	0,0249	0,1814	1,6259
1,960	1,7683	7,3530	29,5448	0,0248	0,1820	1,6326
1,965	1,7722	7,4103	29,5873	0,0247	0,1827	1,6393
1,970	1,7762	7,4680	29,6297	0,0246	0,1834	1,6461
1,975	1,7801	7,5262	29,6720	0,0245	0,1840	1,6529
1,980	1,7841	7,5849	29,7141	0,0244	0,1847	1,6597
1,985	1,7880	7,6441	29,7561	0,0243	0,1854	1,6666
1,990	1,7920	7,7037	29,7980	0,0242	0,1861	1,6735
1,995	1,7960	7,7638	29,8397	0,0241	0,1867	1,6805
2,000	1,8000	7,8244	29,8812	0,0240	0,1874	1,6875
2,005	1,8040	7,8856	29,9227	0,0239	0,1881	1,6946
2,010	1,8080	7,9471	29,9640	0,0238	0,1888	1,7016
2,015	1,8120	8,0092	30,0051	0,0237	0,1894	1,7088
2,020	1,8161	8,0718	30,0462	0,0236	0,1901	1,7160
2,025	1,8201	8,1349	30,0870	0,0235	0,1908	1,7232
2,030	1,8242	8,1985	30,1278	0,0234	0,1915	1,7305
2,035	1,8282	8,2627	30,1684	0,0233	0,1922	1,7378
2,040	1,8323	8,3273	30,2089	0,0232	0,1929	1,7451
2,045	1,8364	8,3925	30,2492	0,0231	0,1936	1,7525
2,050	1,8405	8,4581	30,2894	0,0230	0,1942	1,7600
2,055	1,8446	8,5244	30,3295	0,0229	0,1949	1,7675

M	T/t	P/p	V/root(T)	m root(T)/AP	m root(T)/Ap	A/A*
1,690	1,5712	4,8622	27,0255	0,0304	0,1480	1,3283
1,695	1,5746	4,8989	27,0763	0,0303	0,1486	1,3329
1,700	1,5780	4,9360	27,1269	0,0302	0,1492	1,3376
1,705	1,5814	4,9734	27,1774	0,0301	0,1498	1,3423
1,710	1,5848	5,0111	27,2277	0,0300	0,1504	1,3471
1,715	1,5882	5,0491	27,2779	0,0299	0,1510	1,3519
1,720	1,5917	5,0874	27,3279	0,0298	0,1516	1,3567
1,725	1,5951	5,1260	27,3777	0,0297	0,1522	1,3616
1,730	1,5986	5,1650	27,4274	0,0296	0,1528	1,3665
1,735	1,6020	5,2043	27,4769	0,0295	0,1534	1,3715
1,740	1,6055	5,2439	27,5262	0,0294	0,1540	1,3764
1,745	1,6090	5,2839	27,5754	0,0293	0,1546	1,3814
1,750	1,6125	5,3241	27,6244	0,0292	0,1552	1,3865
1,755	1,6160	5,3647	27,6733	0,0290	0,1558	1,3916
1,760	1,6195	5,4057	27,7220	0,0289	0,1564	1,3967
1,765	1,6230	5,4470	27,7705	0,0288	0,1570	1,4019
1,770	1,6266	5,4886	27,8189	0,0287	0,1577	1,4070
1,775	1,6301	5,5306	27,8672	0,0286	0,1583	1,4123
1,780	1,6337	5,5729	27,9152	0,0285	0,1589	1,4175
1,785	1,6372	5,6156	27,9632	0,0284	0,1595	1,4228
1,790	1,6408	5,6587	28,0109	0,0283	0,1601	1,4282
1,795	1,6444	5,7020	28,0585	0,0282	0,1608	1,4336
1,800	1,6480	5,7458	28,1060	0,0281	0,1614	1,4390

M1	Pt1/P1	Tt1/T1	M2	P2/P1	T2/T1	ρ2/ρ1	Pt2/P2	Pt2/Pt1
1,600	4,2504	1,5120	0,6684	2,8200	1,3880	2,0317	1,3493	0,8952
1,605	4,2820	1,5152	0,6669	2,8387	1,3914	2,0401	1,3475	0,8933
1,610	4,3139	1,5184	0,6655	2,8574	1,3949	2,0485	1,3458	0,8915
1,615	4,3461	1,5216	0,6640	2,8763	1,3983	2,0569	1,3441	0,8896
1,620	4,3785	1,5249	0,6625	2,8951	1,4018	2,0653	1,3425	0,8877
1,625	4,4112	1,5281	0,6611	2,9141	1,4053	2,0736	1,3408	0,8857
1,630	4,4442	1,5314	0,6596	2,9330	1,4088	2,0820	1,3392	0,8838
1,635	4,4774	1,5346	0,6582	2,9521	1,4123	2,0903	1,3375	0,8819
1,640	4,5110	1,5379	0,6568	2,9712	1,4158	2,0986	1,3359	0,8799
1,645	4,5448	1,5412	0,6554	2,9904	1,4193	2,1069	1,3343	0,8780
1,650	4,5789	1,5445	0,6540	3,0096	1,4228	2,1152	1,3328	0,8760
1,655	4,6132	1,5478	0,6526	3,0289	1,4263	2,1235	1,3312	0,8740
1,660	4,6479	1,5511	0,6512	3,0482	1,4299	2,1318	1,3297	0,8720
1,665	4,6829	1,5544	0,6498	3,0676	1,4334	2,1401	1,3281	0,8700
1,670	4,7181	1,5578	0,6485	3,0870	1,4369	2,1484	1,3266	0,8680
1,675	4,7537	1,5611	0,6471	3,1066	1,4405	2,1566	1,3251	0,8660
1,680	4,7896	1,5645	0,6458	3,1261	1,4440	2,1649	1,3236	0,8639
1,685	4,8257	1,5678	0,6445	3,1458	1,4476	2,1731	1,3222	0,8619
1,690	4,8622	1,5712	0,6431	3,1654	1,4512	2,1813	1,3207	0,8599
1,695	4,8989	1,5746	0,6418	3,1852	1,4547	2,1895	1,3193	0,8578
1,700	4,9360	1,5780	0,6405	3,2050	1,4583	2,1977	1,3179	0,8557
1,705	4,9734	1,5814	0,6393	3,2249	1,4619	2,2059	1,3165	0,8536
1,710	5,0111	1,5848	0,6380	3,2448	1,4655	2,2141	1,3151	0,8516
1,715	5,0491	1,5882	0,6367	3,2648	1,4691	2,2222	1,3137	0,8495
1,720	5,0874	1,5917	0,6355	3,2848	1,4727	2,2304	1,3124	0,8474

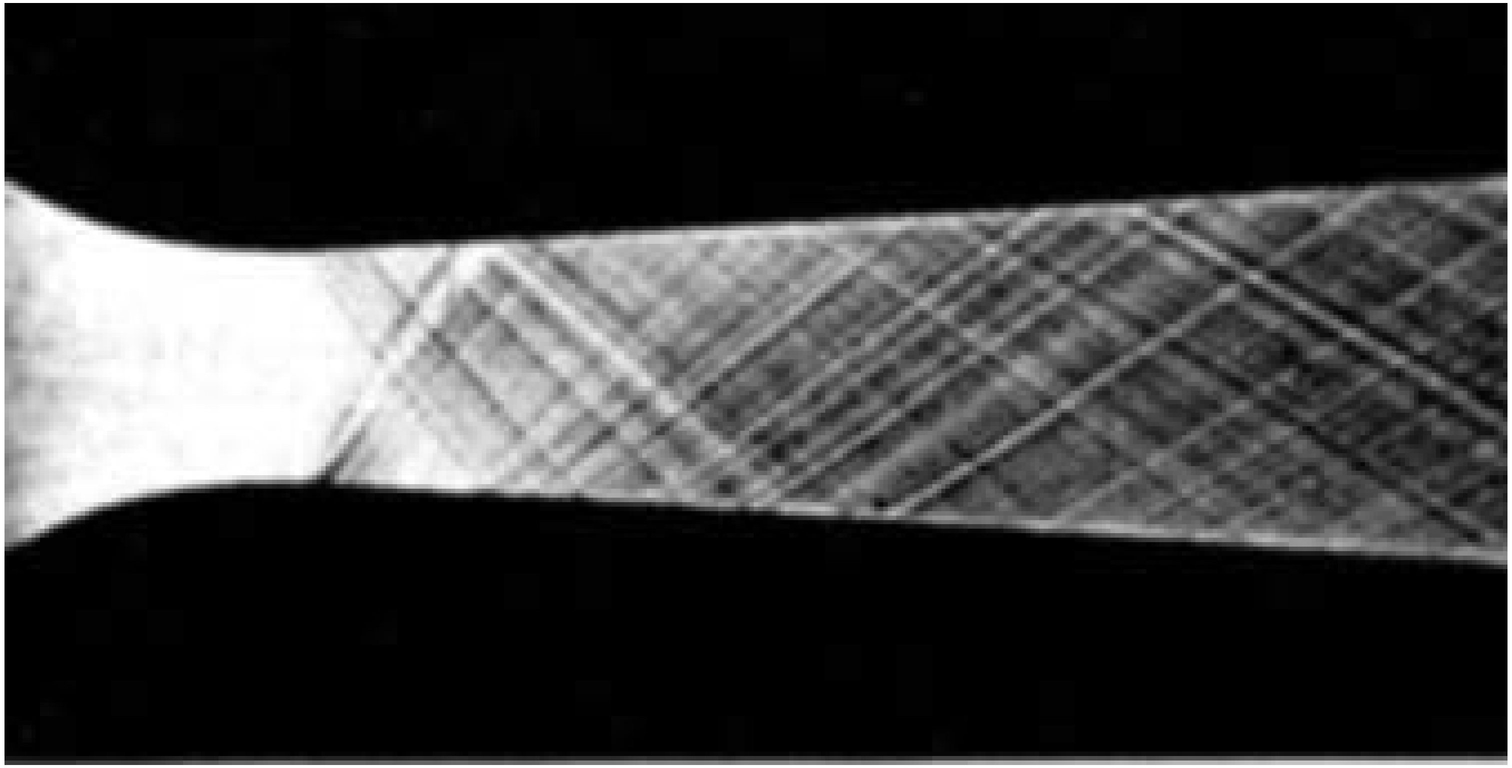
M	T/t	P/p	V/root(T)	m root(T)/AP	m root(T)/Ap	A/A*
0,520	1,0541	1,2024	10,1525	0,0310	0,0373	1,3034
0,525	1,0551	1,2066	10,2450	0,0312	0,0377	1,2948
0,530	1,0562	1,2108	10,3374	0,0314	0,0380	1,2865
0,535	1,0572	1,2151	10,4297	0,0316	0,0384	1,2783
0,540	1,0583	1,2194	10,5218	0,0318	0,0388	1,2703
0,545	1,0594	1,2238	10,6138	0,0320	0,0392	1,2625
0,550	1,0605	1,2283	10,7056	0,0322	0,0396	1,2549
0,555	1,0616	1,2327	10,7973	0,0324	0,0399	1,2475
0,560	1,0627	1,2373	10,8889	0,0326	0,0403	1,2403
0,565	1,0638	1,2419	10,9803	0,0328	0,0407	1,2332
0,570	1,0650	1,2465	11,0716	0,0330	0,0411	1,2263
0,575	1,0661	1,2512	11,1627	0,0331	0,0415	1,2196
0,580	1,0673	1,2560	11,2537	0,0333	0,0418	1,2130
0,585	1,0684	1,2608	11,3445	0,0335	0,0422	1,2066
0,590	1,0696	1,2656	11,4352	0,0337	0,0426	1,2003
0,595	1,0708	1,2705	11,5257	0,0338	0,0430	1,1942
0,600	1,0720	1,2755	11,6161	0,0340	0,0434	1,1882
0,605	1,0732	1,2805	11,7063	0,0342	0,0438	1,1824
0,610	1,0744	1,2856	11,7964	0,0344	0,0442	1,1767
0,615	1,0756	1,2907	11,8863	0,0345	0,0445	1,1711
0,620	1,0769	1,2959	11,9760	0,0347	0,0449	1,1656
0,625	1,0781	1,3012	12,0656	0,0348	0,0453	1,1603
0,630	1,0794	1,3065	12,1551	0,0350	0,0457	1,1552
0,635	1,0806	1,3119	12,2444	0,0351	0,0461	1,1501
0,640	1,0819	1,3173	12,3335	0,0353	0,0465	1,1451
0,645	1,0832	1,3228	12,4225	0,0354	0,0469	1,1403

Linhas de Mach



UNIVERSITY OF LIVERPOOL

http://www.liv.ac.uk/researchintelligence/issue13/macro.html

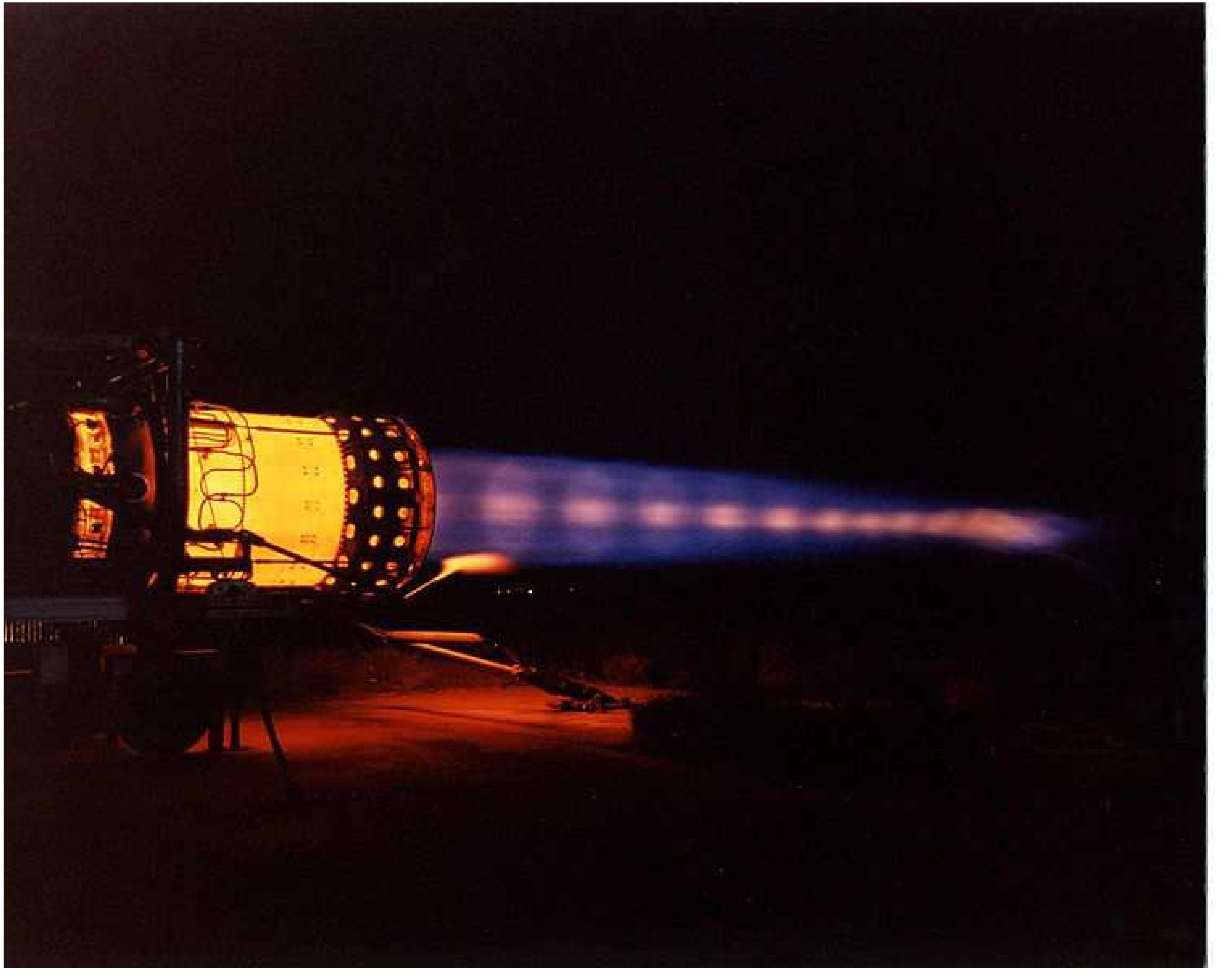


PENN STATE
COLLEGE OF ENGINEERING MECHANICAL & NUCLEAR ENGINEERING
http://www.mne.psu.edu/psgdl/Courses.html

SR-71 (Lockheed)
http://en.wikipedia.org/wiki/File:SR-71_Blackbird_afterburn.jpg

F-16 (Lockheed)

http://en.wikipedia.org/wiki/File:South_Carolina_F-16_taking_off_in_Afghanistan.jpg



J-58 (Pratt & Whitney)
http://en.wikipedia.org/wiki/File:J58_AfterburnerT.jpeg

Exercício

- Um duto convergente-divergente possui as seguintes condições de estagnação: Temperatura = 500K e Pressão = 10^6Pa. A área da garganta vale 0,01 m^2 e o número de Mach na saída é 2,0. (a) Determine a vazão de ar. (b) Determine a área e a temperatura na saída.

Exercício

- Ar em um tanque a 2.10^5 Pa se expande em um duto convergente-divergente com área da garganta = $15cm^2$ e área de saída = $30cm^{2.}$ Na parte divergente, em $A=20cm^2$ há uma onda de choque. Calcule a pressão na saída.