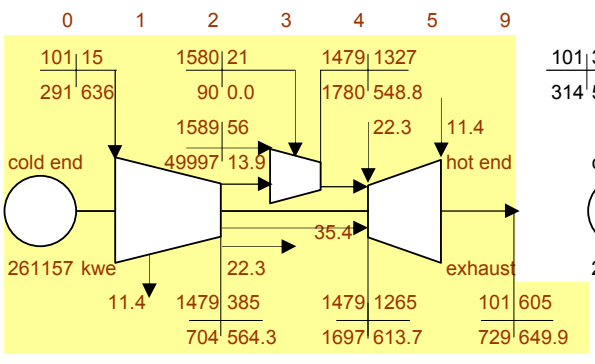
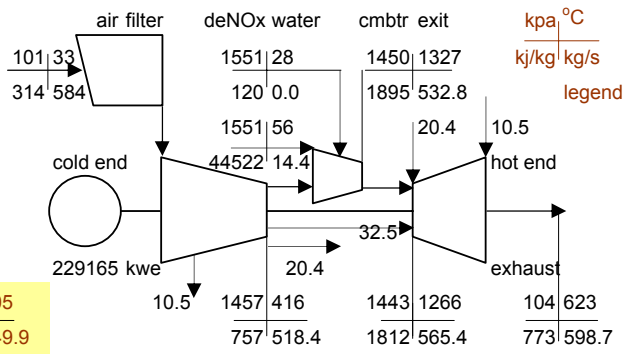
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
2	**OEM design points**				**Off design conditions:**			**stn#**	**Calculations:**		kpa	k	m^3/kg	R	cp	cp/cv	
3	Engine model		9531FA		actual fuel apply		nat-gas	0	ISO standard air		101	288	0.825	288	1.009	1.400	
4	shaft speed:rpm		3000		site amb-p:kpa		101.3		site ambient air		101	306	0.905	292	1.027	1.397	
5	ISO std-p:kpa		101.3		site amb-t:°C		33	1	air filter outlet		100	306	0.915	292	1.027	1.397	
6	ISO std-t:°C		15		relative humidity		85%	2	compressor inle		100	306	0.916	292	1.027	1.397	
7	ISO std RH:		60%		vapor/air:kg/kg		0.027		compressor exit		1462	689	0.137	292	1.0984	1.3616	
8	vapor/air:kg/kg		0.006					3	air exit diffuser		1457	689	0.138	292	1.098	1.362	
9	design flow:kg/s		636		**Actual test corrections:**				combustor zone		1450	1600	0.335	304	1.380	1.282	
10	compress-ratio:		14.60		air inlet filter Δp		1.0%		$deNO_x$ water		1450	1600	0.335	304	1.380	1.282	
11	turbine fire t:°C		1327		engine inlet Δp		0.2%	4	combustor exit		1443	1600	0.337	304	1.380	1.282	
12	turbine exit t:°C		605		compr-exit Δp		0.3%		turbine SOT exit		1443	1540	0.324	304	1.371	1.284	
13	ISO output:kWe		261157		combustor Δp		0.5%	5	turbine b/f cool		104	919	2.674	304	1.2465	1.3219	
14	heat rate kj/kWh		9564		exhaust exit Δp		3.0%		turbine aft cool		104	905	2.632	304	1.243	1.323	
15	compress stage		18		actual cmpr pr		14.425		turbine exhaust		104	897	2.608	304	1.240	1.324	
16	stage pr-ratio:		1.161		actual turbine pr		13.811										
17	polytropic eff:		0.874		actual fuel ratio		0.028		**Flow parameter**		Mach	flow:Q	$A:m^2$	V:m/s	Upit:m/s	Rpit:m	
18	turbine pr-ratio:		14.60		actual cmpr eff		0.874	2	cmpr 1st stage:		0.62	34.10	2.995	210	313	0.997	
19	turbine stages:		3		actual turb eff		0.884	3	cmpr last stage:		0.17	11.19	0.832	87	297	0.947	
20	stage pr-ratio:		2.444		actual cmbtr eff		0.999		cmbtr zone1:		0.02	1.41	5.32	21	0	1.301	
21	polytropic eff:		0.884		actual mech eff		0.993		cmbtr zone2:		0.10	6.78	2.170	52	0	1.367	
22	specified fuel		methane		actual altern eff		0.986	4	turbine stage-1:		0.19	12.27	1.181	149	375	1.195	
23	CH_4 LHV:kj/kg		49997		actual flow:kg/s		584	5	turbine stage-3:		0.69	34.71	5.011	404	479	1.524	
24	fuel/air ratio:		0.025														
25	fuel/H_2O fwd:kpa		1551		**engine cooling coef:**				**data iteration:**		cmpr	turbine		**combustor evaluation**			
26	fuel fwd temp:°C		56		total cmpr bleed		0.1127		isentropic eff:		0.825	0.914		inner vol:m^3		0.038	
27	mechanical eff:		0.993		cmpr to stage-3		0.0180		mean-T cp/cv:		1.362	1.322		outer vol:m^3		0.054	
28	combustor eff:		0.999		cmpr to stage-2		0.0350		mean Temp cp:		1.098	1.247		zone-1 flow:kg/s		205.8	
29	alternator eff:		0.986		cmpr to stage-1		0.0557							zone-2 flow:kg/s		174.4	
30	**engine cooling coef:**				nett cmbtr inlet		0.8873		**engine sizing**		cmpr	turbine		zone-3 flow:kg/s		152.6	
31	total cmpr bleed		0.1127		total cmbtr exit		0.9120		rotor-ϕ/blade-h		mm	mm					
32	cmpr to stage-3		0.0180						1st stage hub		1425	2077		**Performance Analysis:**			
33	cmpr to stage-2		0.035		**Optional BOP functions:**				1st stage pitch		1935	2271		cmpr work:kWs		245118	
34	cmpr to stage-1		0.0557		$deNO_x$ H_2O:kg/s		0		1st stage tip		2446	2465		turb power:kWs		474282	
35	nett cmbtr inlet		0.8873		H_2O/air:kg/kg		0.0000		1st stage blade		511	194		nett power:kWe		229165	
36	total cmbtr exit		0.9092		deNOx H_2O:cp		4.1749		last stage hub		1668	2298		fuel flow:kg/s		14.428	
37	**Off design GT exh flow:**				**Off design GT exh energy:**				last stage pitch		1837	2896		fuel rate:kg/kWh		0.227	
38	exh gas:kg/kg		50.1		exh heat:kj/kg		773.3		last stage tip		2007	3493		heat efficiency		0.357	
39	exh air:kg/kg		51.2		exh energy:kj/s		451766		last stage blade:		170	597		heat rate:kj/kWh		10091	
40	exh flow:kg/s		598.7		engine thrust:N		241743										
41																	
42	**OEM design point: (ISO 100% methane fuel)**								**Off design (change fuel / ambient condition)**								





HRSG-Dual Pressure (non RH); forced circulation-vertical flue flow; single steam flow-HP-exh mix LP-new to LP turbine

GT exhaust parameter

gt exit flow: kg/s	598.7
gt exit temp: °C	623.4
gt exit enth:kj/kg	773.3

HRSG design analysis:

heat transf eff	92.0%

HP design p&t profile:

		rated:
HP sph1:kpa	10674	10674
HP sph1:oC	523.6	523.6
sph1-appro:Δt°C	99.8	76.0
sph1:sph2 Δkpa	5.0%	NA
HP sph2:kpa	11208	NA
HP sph2:°C	460	460
sph2-appro:Δt°C	140.8	125
hpev>sph Δkpa	5.0%	NA
HP evap:kpa	11768	NA
HP evap:°C	323.2	319
hpev-pinch:Δt°C	8	8
hpec>evap Δkpa	5.0%	NA
HP econ:kpa	12356	NA
HP econ-exit:°C	305.0	305
hpec-appro:Δt°C	69.4	12

LP design p&t profile:

LP sph:kpa	552.7	552.7
LP sph:°C	283.7	283.7
lpsh-appro:Δt°C	99.2	38
lpev>sph Δkpa	20.0%	NA
LP evap:kpa	663.2	NA
LP evap:°C	162.8	NA
lpev-pinch:Δt°C	22.0	7.4
Deaerator:kpa	594	594
Deaerator:°C	146	146
LP econ:kpa	3200	NA
LP econ-exit:°C	161	NA
lpec-appro:Δt°C	101.4	20

Steam turbine design:

HP stm inlet:kpa	10515	10515
HP stm inlet:°C	537.0	530.6
LP stm inlet:kpa	482.2	482.2
LP stm inlet: °C	280.0	285.6
LP stm exh:kpa	9.00	8
LP stm exh:°C	43.8	NA

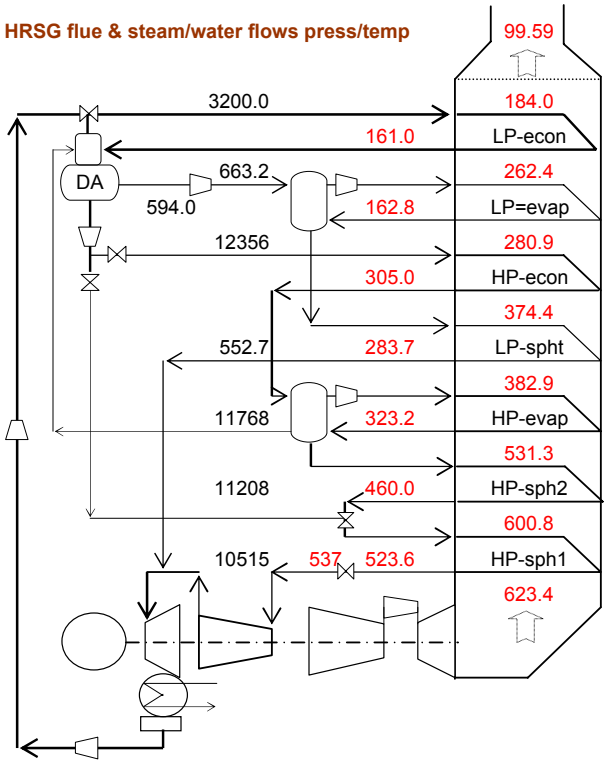
Stm turbine efficiency:

HP turbine	0.88	NA
LP turbine	0.845	NA
mechanical	0.993	NA
alternator	0.99	NA
exh loss:kj/kg	56	NA

HRSG flue gas flow parameters & steam evaporation calculations:

	<steam phase >>				<gas phase >>					m-flow
Heat exchange:	p:kpa	t:°C	st:kj/kg	liq:kj/kg	Q:kj/s	Tp:°C	Tp:kj/kg	ex:kj/kg	exit:°C	m:kg/s
HP sphtr-1	10674	523.6	3426.6		18203	623.4	773.3	745.3	600.8	104.40
HP sphtr-2	11208	460.0	3252.3		58288	600.8	741.6	655.7	531.3	
HP evaporator	11768	323.2	2694.0	1482.3	138325	331.2	383.2	443.1	382.9	104.40
HP economizer	12356	305.0		1369.1	71809	374.4	437.9	328.5	280.9	
LP superheater	552.7	283.7	3029.6		2815	382.9	448.7	438.8	374.4	10.43
LP evaporator	663.2	162.8	2759.7	687.6	22373	184.8	207.1	294.1	262.4	10.43
LP economizer	3200.0	161.0		681.3	57193	183.0	204.2	206.2	184.0	114.84
Deaerator	594.0	146.0		615.0		flue gas discharge temp:			99.59	
bfwp inlet	9.00	43.8		183.3		**Energy: Q=kj/s**	HP	LP	Total	
Evaporation	HP	LP	Total			energy utilized	214816	96997	369007	
Output:kg/hr	375857	37554	413412			counter balance	214816	96997	369007	

HRSG flue & steam/water flows press/temp



HRSG liq/stm states:

Cdn fw-in:kj/kgk	0.6224
Lp-econ in:°C	43.9
Lp-econ:kj/kgk	1.9494
D/A inlet:°C	158.4
D/A liq-s:kj/kjk	1.9269
Lp evap in:°C	158.5
Lp evap:kj/kgk	1.9269
Lp evap sat:°C	162.8
Hp econ in:°C	159.8
Hp econ:kj/kgk	3.2878
Hp econ out:°C	305.0
Hp evap in:°C	304.7
Hp evap sat:°C	323.2

Turbine steam states:

HP inlet stm:kj/k	3462.2
HP exh stm:kpa	526.0
HP exh stm:°C	153.8
HP exh-h:kj/kg	2749.8
HP exh-s:kj/kjk	6.802
Isentrop-δh:kj/kg	2735.5
correct θh:kj/kg	2826.4
LP stm:kj/kg	3023.9
Hp+Lp mix:kj/kg	2844.3
LP stm inlet:°C	194.55
LP exh-s:kj/kgk	7.052
Isentrop-δh:kj/kg	2317.8
correct θh:kj/kg	2427.2

attemperation:

rate	1.0%
t:°C	521
kpa	10691
kj/kg	3434

blow down:

HP rate	1.0%
LP rate	1.0%

Steam turbine proper output

kWe	HP	LP	Total
design	64992	40598	105590
actual	62150	40557	102708

GTCC Performance Evaluation

performance	design	actual
power kWe:	334755	331873
heat rate kj/kWh	6908	6968
combine heat ef	0.521	0.517
heat recovery ef	0.817	0.817

circulating water flow

CW inlet t°C	23
CW in/out Δt	8
CW exit t°C	31
CW flow kg/s	3738

A B C D E F G H I J K L M N O P Q

HRSG-Triple Pressure ReHeat; forced circulation-vertical flue flow; single steam flow-HP-exh mix LP-new to LP turbine

GT exhaust parameter

gt exit flow: kg/s	598.7
gt exit temp: °C	623.4
gt exit enth:kj/kg	773.3

HRSG design analysis:

heat transf eff	92%
HP sph1:kpa	11890
HP sph1:oC	537
sph1-appro:Δt°C	86.4
ec>ev>sh Δkpa	2.5%
HP evap:kpa	12187
hpev-pinch:Δt°C	8
HP econ:kpa	12492
HP econ-exit:°C	325.74
hpec-appro:Δt°C	59.4
RH sph2:kpa	2870
RH sph2:°C	537
sph2-appro:Δt°C	15
ec>ev>sh Δkpa	2.5%
RH evap:kpa	2942
rhev-pinch:Δt°C	8
RH econ:kpa	3015.3
RH econ-exit:°C	232.12
rhec-appro:Δt°C	8.0
LP sph3:kpa	472.5
LP sph3:°C	155
lpsh-appro:Δt°C	176
lpev>sph Δkpa	8.0%
LP evap:kpa	510.3
lpev-pinch:Δt°C	8
lpec>evap Δkpa	5.0%
LP econ:kpa	562.61
LP econ-exit:°C	154.34
lpec-appro:Δt°C	88
Deaerator:kpa	535.82
Deaerator:°C	152.47

Steam turbine design:

HP stm inlet:kpa	11600
HP stm inlet:°C	537
RH stm inlet:kpa	2800
RH stm inlet:°C	537
LP stm inlet:kpa	450
LP stm inlet: °C	152
LP stm exh:kpa	9.00
LP stm exh:°C	43.8

Stm turbine efficiency:

HP turbine	0.87
LP turbine	0.91
mechanical	0.99
alternator	0.98

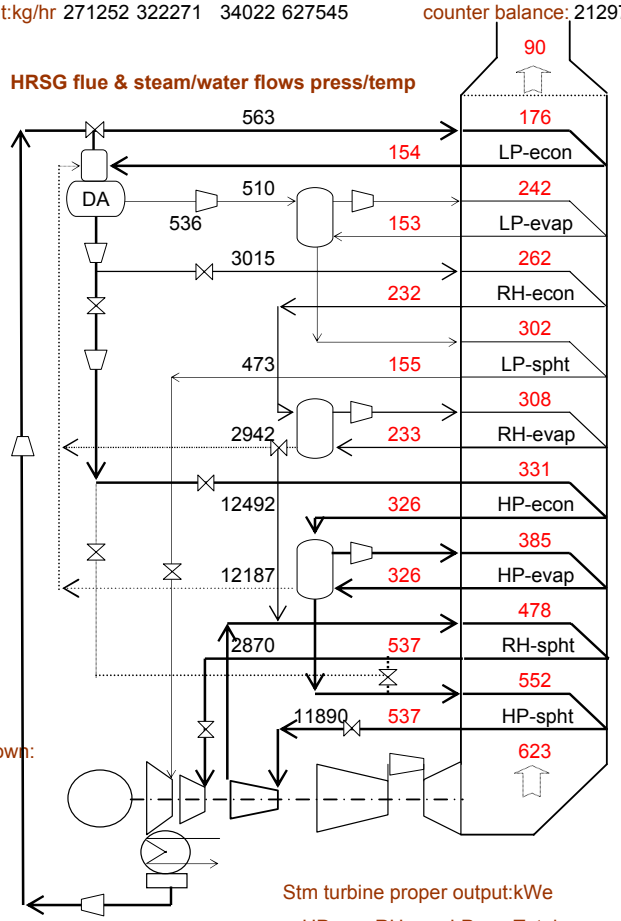
HRSG flue gas flow parameters & steam evaporation calculations:

Heat exchange:	<steam phase >> p:kpa	t:°C	st:kj/kg	liq:kj/kg	<gas phase >> Q:kj/s	Tp:°C	Tp:kj/kg	ex:kj/kg	exit:°C	m-flow m:kg/s
HP sphtr-1	11890	537	3447		57436	623.4	773.3	685.0	552.2	75.3
RH sphtr-2	2870	537	3540		66067	552.2	674.1	583.5	478.0	75.3
HP evaporator	12187	326	2685	1499	89469	333.8	386.6	446.0	385.1	
HP economizer	12492	326		1498	37485	385.1	451.6	388.4	331.2	
RH evaporator	2942	233	2802		25537	240.8	272.9	349.1	308.0	14.2
RH economizer	3015	232	1000	1000	31272	240.1	272.2	300.9	261.9	
LP superheater	473	155	2757		83	331.2	383.3	349.0	301.6	
LP evaporator	510	153	2748	643	19823	160.6	179.2	270.5	242.4	9.5
LP economizer	563	154		651	46284	242.4	274.8	199.3	175.8	174.3
Deaerator	536	152	643	643	flue gas discharge temp:				89.884	
bfwp inlet	9.00	44	2581	183	**Energy**:Q=kj/s	HP	RH	LP	Total	

Evaporation	HP	RH	LP	Total
Output:kg/hr	271252	322271	34022	627545

energy utilized:	212972	63022	51178	373455
counter balance:	212972	63022	51178	373455

HRSG flue & steam/water flows press/temp



HRSG liq/stm states:

Cdn fw-in:kj/kgk	0.6224
Lp-econ in:°C	43.8
Lp-econ:kj/kgk	1.8856
D/A inlet:°C	154.3
Lp evap sat:°C	152.6
Rh econ in:°C	154.62
Rh evap sat:°C	232.8
Hp econ in:°C	155.7
Hp econ:kj/kgk	3.5059
Hp econ out:°C	325.7
Hp evap sat:°C	325.8

Turbine steam states:

HP stm-in:kj/kg	3450.6
HP exh stm:kpa	2941.8
HP exh stm:°C	233
HP exh-s:kj/kjk	6.191
HP exh-h:kj/kg	2802
HP-isen-δh:kj/kg	2798
correct θh:kj/kg	2882.8
RH stm-in:kj/kg	3540.9
RH exh stm:°C	147.9
RH exh-s:kj/kjk	6.855
RH exh-h:kj/kg	2743
RH-isen-δh:kj/kg	2743
correct θh:kj/kg	2814.7
LP stm-in:kj/kg	2752.2
Rh+Lp mix:kj/kg	2808.7
LP exh-s:kj/kgk	7.006
LP-isen-δh:kj/kg	2206
correct θh:kj/kg	2256
Lp exh loss kj/kg	60

blowdown:

HP%	1
RH%	1
LP%	1

Stm turbine proper output:kWe

	HP	RH	LP	Total	
	41507	63074	47353	151935	design
	39457	60558	47304	147319	actual

chilling water flow	in-t°C	Δt°C	out-t°C	kg/s
	32	8	40	12246

	spray	HP	RH
rate		1.0%	1.0%
t:°C		527	524
kpa		11896	2851
kj/kg		3423	3512

GTCC output:	design	actual
total power kWe	381100	376484
heat rate kj/kWh	6068	6142
GTCC heat eff:	0.593	0.586
heat recovery ef	0.827	0.827

Fuel lab analysis:

second	temp
referenc	15.56
referenc	101.6
zero en	0.01
gas mix	weight
methane	0.848
ethane	0.027
propane	0.010
I-butane	0.002
n-butane	0.002
-pentan	0.001
ı-pentan	0.001
n-hexan	0.002
bon dio	0.098
nitrogen	0.009
oxygen	0.000
total	1.000

heating values:

HHV	LHV
49408	44522
992	894

Ultimate analysis:

carbon	0.698
hydroge	0.222
oxygen	0.071
nitrogen	0.008
sulfur	0.000
water	0.000
total	1.000

gas properties:

mol-wt	17.65
gas ρ	0.61
gas R	471

gas mole ratio:

H/C	3.785
C	1.000
H	3.785
N/C	0.010
N	0.010
S/C	0.000
S	0.000
$C_4H_4N_2$	0.02
C_4H_4S	0.00

fluegas content:

second	temp
referenc	15.56
referenc	101.6
zero en	0.01
gas mix	weight
carbon	0.031
atmospl	0.734
oxygen	0.136
sulfur di	0.000
water	0.099
total	1.000

fuel combustion:

θair:kg/kg	15.33
zone1 t:k	2772
zone2 t:k	2314
zone3 t:k	1600
1st Xair	1.075
2nd Xair	1.268
total Xair	2.343
flue R	304

Combustion stoichiometry:

mole	x	$y/_2$	$x+y/_4$
CH_4	84.8	169.6	169.6
C_2H_6	5.4	8.1	9.5
C_3H_8	2.9	3.9	4.9
C_4H_{10}	1.9	2.4	3.1
C_5H_{12}	0.9	1.0	1.4
C_6H_{14}	1.1	1.3	1.7
sum	97.0	186.3	190.2

Fuel to fluegas analysis:

gas	kg/kg	m^3/kg	ratio
CO_2	1.668	1.277	0.13
N_2	8.619	6.599	0.70
SO_2	0.000	0.000	0.00
H_2O	2.087	1.598	0.17
θ-flue	12.374	9.475	
prime flue	13.191	10.107	
final flue	27.018	20.800	
θair/flue	10.901	8.431	
θair/LHV	15.079	11.662	

Heat formation table:

mole	mol wt	kj/mol
C	12.01	-717
CO_2	44.01	394
H	1.01	-218
H_2O-l	18.02	286
H_2O-g	18.02	242
O	16.00	-249
N	14.01	-473
NO_2	46.01	-33
S	32.06	-276
SO_2	64.12	297
$C_4H_4N_2$	80.09	140
C_4H_4S	84.14	81
fuel	15.97	255

Benson Δh_f 252

group	kcal/mol	kj/mol
P:CH_3	10.01	41.91
S:CH_2	4.99	20.89
T:CH	2.03	8.50
Q:C	0.12	0.50

Engine design point evaluation (ISO CH_4):

	gas-R	m-T cp	cp/cv	stg-pr	isen-eff	inlet-p	exit-p	inlet-T	exit-T
cmpr	288	1.071	1.368	1.161	0.824	101	1479	288	658
turbine	294	1.203	1.330	2.444	0.915	1479	101	1538	900

Engine	compressor		turbine rotor	
stage	1st	last	1st	last
Load	0.238	0.264	2.013	1.238
pr coef	1.112	0.878	0.419	0.554
flow:Q	34.33	11.26	12.49	35.51
sizing	1st	last	1st	last
A:m^2	3.104	0.979	1.384	5.434
Rhub	0.712	0.834	1.038	1.149
Rpitch	0.968	0.919	1.135	1.448
Rtip	1.223	1.003	1.232	1.746
blade	0.511	0.170	0.194	0.597
hub/tip	0.583	0.831	0.843	0.658
Mach	0.62	0.17	0.19	0.69

speed	1st	last	1st	last
V:m/s	202	84	146	393
V/Upit	0.67	0.29	0.41	0.86
Uhub	224	262	326	361
Upitch	304	289	357	455
Utip	384	315	387	549
reMhub	0.76	0.54	0.46	0.92
reMpit	0.86	0.59	0.50	1.03
reMtip	0.98	0.64	0.53	1.15

Cmbtr	θair	z1-Xair	z2-Xair
	17.23	1.139	1.234
flame-T	SOT	LHV	FAR
2699	1600	49997	0.025

combustor flow	design	off-des
intensity:kW/m^3	35590	38909
zone1 flow:kg/s	211	206
zone2 flow:kg/s	199	179
zone3 flow:kg/s	168	148

Off-design engine speed evaluation

	compressor		turbine rotor	
stage	1st	last	1st	last
pr coef	1.112	0.878	0.419	0.554
Mach	0.62	0.17	0.19	0.69
V/Upit	0.67	0.29	0.40	0.84
Uhub	224	262	326	361
Upitch	313	297	375	479
Utip	384	315	387	549
reMhub	0.75	0.53	0.46	0.91
reMpit	0.86	0.59	0.51	1.05
reMtip	0.96	0.63	0.53	1.14

Combustor design/off-design points

	design point		off-design	
zone	inner	outer	inner	outer
Load	1.5	1.5	1.5	1.5
Mach	0.020	0.100	0.020	0.100
flow:Q	1.429	6.854	1.405	6.740
A:m^2	5.183	1.463	5.317	1.416
V:m/s	21	50	21	52
flow:kg/s	406	173	380	153
vol:m^3	0.917	1.340	0.796	1.147
radius:m	1.284	1.330	1.301	1.344
length:m	0.714	1.008	0.612	0.853
time:sec	0.035	0.020	0.029	0.016

NO_X emission calculation

max CO_2 / LHV	0.1327
rel-O_2 ratio / LHV	#####
flue kg/kg / LHV	16.080
flue m^3/kg / LHV	12.933
flue desity kg/m^3	1.2433
prime combustion	
prime NO_X kg/kg	0.0023
prime NO_X mg/m^3	224.54
final combustion	
final NO_X kg/kg	0.0046
final NO_X mg/m^3	220.41