GasTurb

Turbojet Deck

Joachim Kurzke

Turbojet Deck

Steady State Performance

by Joachim Kurzke

Turbojet Deck

Printed in Germany

Table of Contents

1 GasTurb Computer Deck

The GasTurb Turbojet Deck is a computer deck as defined in the SAE Aerospace Standard AS681. The actual engine subroutine is contained in a Dynamic Link Library (DLL). The use of the engine subroutine is demonstrated both with a Delphi test main program and with an Excel macro. The Dynamic Link Library can be used with any other 32-bit Windows program.

The data describing the engine are created with GasTurb 12 as an Engine Model File which is loaded during the Turbojet Deck initialization process. The Engine Model File contains all data necessary for doing off-design simulations, both for steady state and transient operation. Maximum and minimum limiters as well as bleed schedules must be defined in the engine model. It is strongly recommended to check this model thoroughly with GasTurb 12 before using it with the Turbojet Deck DLL.

Transient simulations can employ the control system as defined in the GasTurb 12 model or run to a specified fuel flow or spool speed.

2 Engine Description

With this generic computer deck the performance of single spool turbojet engines without afterburner can be calculated. Which engine is modeled in particular depends on the Engine Model File created with GasTurb 12.

3 Program Description

The Turbojet Deck has been developed with Delphi XE4 running under Windows 8. The test main program has a standard windows user interface and calls functions from the Turbojet Deck DLL which contains the actual engine simulation model. An alternative use of the Turbojet Deck is shown as an Excel application in the file TurbojetDeckDemo.xls

4 Program Setup

4.1 General

The Turbojet Deck calls functions from a DLL which can be used with any Windows program. In the test main program this DLL is employed by a Delphi program, in the file TurbojetDeckDemo.xls the functions of the DLL are called from an Excel macro. Before commencing with the engine simulation the functions in the DLL must be initialized. During initialization an Engine Model File created with GasTurb 12 is read from file and evaluated. The required organization of the files is as summarized in the table below. Note that the Data Directory can be the same as the DLL Directory.

DLL Directory	Data Directory
TurbojetDeckLib.DLL	An Engine Model File, created with GasTurb 12
LoadOptions.NMS	Component map data files referenced in the Engine Model File
Turbojet.NMS	Fuels.gtb and all files referenced in Fuels.gtb

4.2 DLL Interface

The DLL contains the functions and procedures (subroutines) listed in the table. Note that when declaring the functions and subroutines in a VBA program within Excel, for example, the expression {Path to the DLL} in the table below must be replaced by the actual path to the DLL on the users machine.

Delphi	Visual Basic for Applications (VBA)
function GetDLLVersion : double;	Declare **Function** GetDLLVersion Lib "{Path to the DLL}\TurbojetDeckLib.dll" () As Double
procedure WriteFIXIN (ZCASEFI,ZALTFI,ZDTAMBFI,ZERM1AFI,ZPWXHFI, ZPAMBFI,ZPCFI, ZPLAFI,ZP1AFI,ZRCFI,SERAMFI, SIMFI,ZTAMBFI,ZT1AFI,ZWB3FI,ZWB3QFI,ZXMFI, ZTIMEFI : double);	Declare **Sub** WriteFIXIN Lib "{Path to the DLL}\TurbojetDeckLib.dll" (**ByVal** ZCASEFI#, **ByVal** ZALTFI#, **ByVal** ZDTAMBFI#, **ByVal** ZERM1AFI#, **ByVal** ZPWXHFI#, **ByVal** ZPAMBFI#, **ByVal** ZPCFI#, **ByVal** ZPLAFI#, **ByVal** ZP1AFI#, **ByVal** ZRCFI#, **ByVal** SERAMFI#, **ByVal** SIMFI#, **ByVal** ZTAMBFI#, **ByVal** ZT1AFI#, **ByVal** ZWB3FI#, **ByVal** ZWB3QFI#, **ByVal** ZXMFI#, **ByVal** ZTIMEFI#)
procedure ReadFIXIN (**var** ZCASEFI,ZALTFI,ZDTAMBFI,ZERM1AFI, ZPWXHFI,ZPAMBFI,ZPCFI,ZPLAFI,ZP1AFI,ZRCFI, SERAMFI,SIMFI,ZTAMBFI,ZT1AFI,ZWB3FI,ZWB3QFI, ZXMFI,ZTIMEFI : double);	Declare **Sub** ReadFIXIN Lib "{Path to the DLL}\TurbojetDeckLib.dll" (ZCASEFI#, ZALTFI#, ZDTAMBFI#, ZERM1AFI#, ZPWXHFI#, ZPAMBFI#, ZPCFI#, ZPLAFI#, ZP1AFI#, ZRCFI#, SERAMFI#, SIMFI#, ZTAMBFI#, ZT1AFI#, ZWB3FI#, ZWB3QFI#, ZXMFI#, ZTIMEFI#)
procedure WriteVARIN (ZHUMIDVI,ZFHVVI,ZFNVI,ZWFVI,ZXNRPMVI, ZWRCQ2VI,SESTVI,ZBTACVI,ZRXNHVI,ZT4VI, ZBTATVI,ZDTRCVI,STRANSVI,ZCTRCPVI,ZCTRCDVI, ZCTRCIVI : double);	Declare **Sub** WriteVARIN Lib "{Path to the DLL}\TurbojetDeckLib.dll" (**ByVal** ZHUMIDVI#, **ByVal** ZFHVVI#, **ByVal** ZFNVI#, **ByVal** ZWFVI#, **ByVal** ZXNRPMVI#, **ByVal** ZWRCQ2VI#, **ByVal** SESTVI#, **ByVal** ZBTACVI#, **ByVal** ZRXNHVI#, **ByVal** ZT4VI#, **ByVal** ZBTATVI#, **ByVal** ZDTRCVI#, **ByVal** STRANSVI#, **ByVal** ZCTRCPVI#, **ByVal** ZCTRCDVI#, **ByVal** ZCTRCIVI#)

procedure ReadVARIN (**var** ZHUMIDVI,ZFHVVI,ZFNVI,ZWFVI,ZXNRPMVI, ZWRCQ2VI,SESTVI,ZBTACVI,ZRXNHVI,ZT4VI,ZBTATVI, ZDTRCVI,STRANSVI,ZCTRCPVI,ZCTRCDVI,ZCTRCIVI : double);	Declare **Sub** ReadVARIN Lib "{Path to the DLL}\TurbojetDeckLib.dll" (ZHUMIDVI#, ZFHVVI#, ZFNVI#, ZWFVI#, ZXNRPMVI#, ZWRCQ2VI#, SESTVI#, ZBTACVI#, ZRXNHVI#, ZT4VI#, ZBTATVI#, ZDTRCVI#, STRANSVI#, ZCTRCPVI#, ZCTRCDVI#, ZCTRCIVI#)
procedure ReadFIXOUT (**var** NSIFO,AE8FO,FRAMFO,FGFO,FHVFO,FNFO, PB3FO,P7FO,SFCFO,TB3FO,T7FO,WFEFO,WFTFO, W1AFO,W7FO,W2FO,XNHFO,ALTFO,PAMBFO,PLAFO, P1AFO,TAMBFO,T1AFO,XMFO,SMHFO,TIMEFO, ERAM1FO,DTAMBFO,PCFO,RCFO,WB3FO,WB3QFO, PWXHFO : Double);	Declare **Sub** ReadFIXOUT Lib "{Path to the DLL}\TurbojetDeckLib.dll" (NSIFO#, AE8FO#, FRAMFO#, FGFO#, FHVFO#, FNFO#, PB3FO#, P7FO#, SFCFO#, TB3FO#, T7FO#, WFEFO#, WFTFO#, W1AFO#, W7FO#, W2FO#, XNHFO#, ALTFO#, PAMBFO#, PLAFO#, P1AFO#, TAMBFO#, T1AFO#, XMFO#, SMHFO#, TIMEFO#, ERAM1FO#, DTAMBFO#, PCFO#, RCFO#, WB3FO#, WB3QFO#, PWXHFO#)
procedure ReadVAROUT (**var** humidVO,T2VO,T3VO,T4VO,T41VO,T5VO, P3VO,Ps3VO,P5VO,NHDOT,FAR4,LIMCD,BTACVO, RXNHVO,BTATVO,DTRCVO :Double);	Declare **Sub** ReadVAROUT Lib "{Path to the DLL}\TurbojetDeckLib.dll" (humidVO#, T2VO#, T3VO#, T4VO#, T41VO#, T5VO#, P3VO#, Ps3VO#, P5VO#, NHDOT#, FAR4#, LIMCD#, BTACVO#, RXNHVO#, BTATVO#, DTRCVO#)
procedure InitializeEngine (DLLPath,FileName : PChar);	Declare **Sub** InitializeEngine Lib "{Path to the DLL}\TurbojetDeckLib.dll" (ByVal DLLPath$, ByVal Filename$)
procedure SinglePoint;	Declare **Sub** SinglePoint Lib "{Path to the DLL}\TurbojetDeckLib.dll" ()

4.3 DLL Function Call Sequence

DLL Initialization

During initialization of the DLL the files in the DLL directory and in the Engine Model File directory are read. Furthermore, the cycle reference point is calculated which yields all the output quantities for this operating condition. After the call of InitializeEngine all the elements of FIXIN, VARIN, FIXOUT and VAROUT can be read by the DLL calling program:

InitializeEngine

ReadFIXIN

ReadVARIN

ReadFIXOUT

ReadVAROUT

If after the initialization the VARIN property SEST is set to 1, then the following single point calculation will employ as starting values of the iteration the properties ZBTAC, ZRXNH, ZT4, ZBTAT and ZDTRC. It is a good idea to write the results (i.e. the VAROUT properties BTAC, RXNH, BTAT and DTRC) to the corresponding input properties immediately after calling InitializeEngine. Thus there are reasonable estimates for the iteration variables readily available for the use with SEST=1 if convergence problems are encountered.

Using the DLL for steady state simulations

The procedure (subroutine) **SinglePoint** calculates a single cycle point either in steady state (ZTIME=0) or transient mode (ZTIME>0). Before calling the actual simulation function **SinglePoint** the input data stored in the FIXIN and VARIN properties must be transferred to the DLL by calling the procedures **WriteFIXIN** and **WriteVARIN**. After the cycle calculation is finished, the results can be read from the DLL by calling the procedures **ReadFIXOUT** and **ReadVAROUT**:

WriteFIXIN

WriteVARIN

SinglePoint

ReadFIXOUT

ReadVAROUT humid, T2, T3, T4, T41, T5, P3, Ps3, P5, NHDOT, FAR4, LIMCD, BTAC, RXNH, BTAT, DTRC

Using the DLL for transient simulations

The procedure (subroutine) **SinglePoint** calculates a single point in transient mode for the time = ZTIME (defined in FIXIN) which must be greater than the value TIME (defined in VAROUT) of the previously calculated point. The begin of the transient maneuver is the operating condition that was calculated with ZTIME=0 immediately before ZTIME is set to a value greater than zero.

ZTIME=0

repeat

WriteFIXIN

WriteVARIN

SinglePoint

ReadFIXOUT

ReadVAROUT

ZTIME=TIME+delta time

until ZTIME > end time

4.4 Test Main

The Test Main program has been created and compiled with Delphi XE4. It provides a graphical user interface for the functions and procedures in the DLL.

Before commencing with simulations, the DLL must be initialized by loading an Engine Model File which was created with GasTurb 12. Note that the component maps employed in the Engine Model File must be stored in the same directory as the Engine Model File as described on the general introduction to the program setup.

On the steady state input page the input properties for a single point are offered. The input properties are grouped as FIXIN and VARIN, the output properties are shown in the groups FIXOUT and VAROUT.

The transient page of the test main program offers the following three simulation examples:

- A step increase of 10% in fuel flow (GasTurb 12 control system inactive)
- A PLA maneuver with activated control system as described with the Engine Model File
- An example with prescribed spool speed (GasTurb 12 control system inactive)

Each transient maneuver commences with the steady state condition calculated before switching to transient simulations.

4.5 Excel Application

The file TurbojetDeckDemo.xls - which is delivered as part of the software package - demonstrates the use of the Turbojet Deck DLL with Excel.

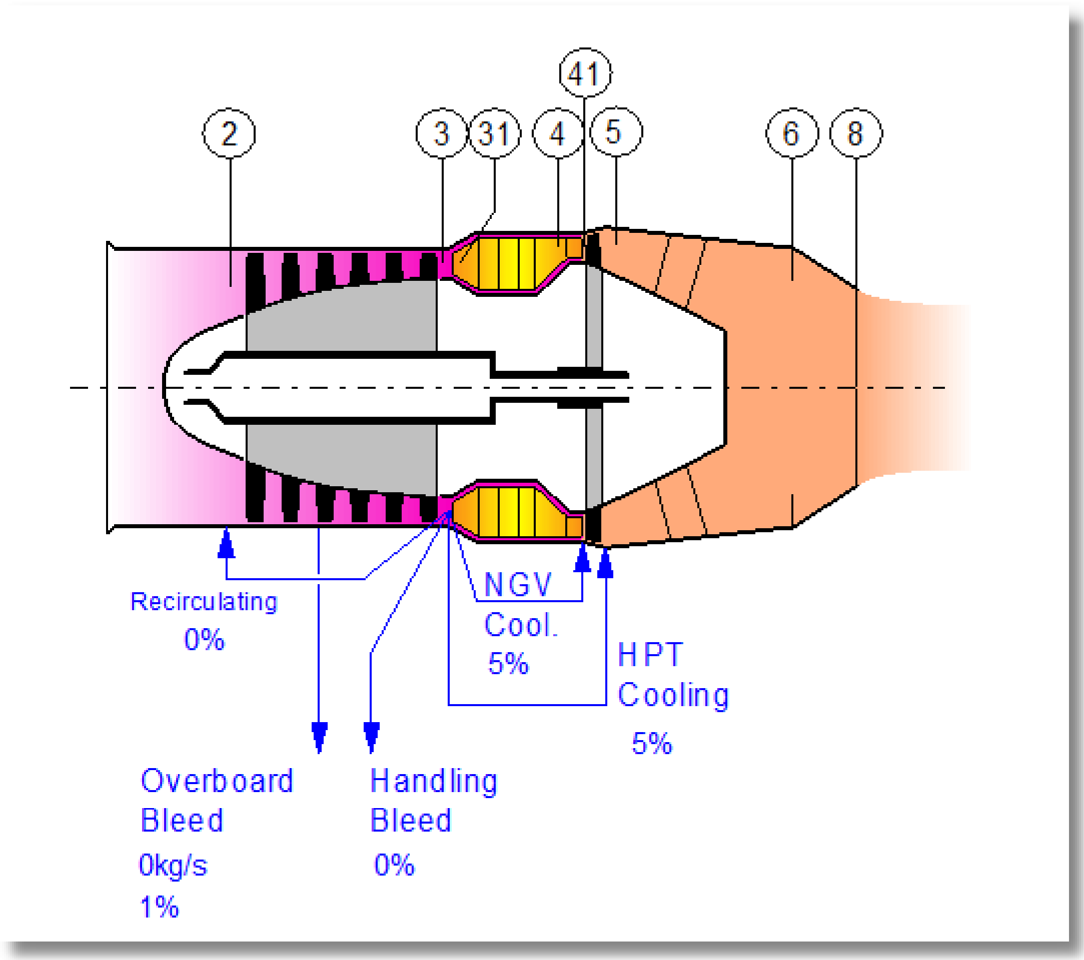
Before running the file TurbojetDeckDemo.xls make sure that the correct path to the DLL is introduced in the declaration section of the VBA program. After starting Excel (macros activated) use Alt+F11 for opening the VBA editor and replace the DLL path information - which is valid only on the computer of the DLL author - with the path to the place where you have stored the DLL on your computer.

The calculation options in the Excel file are essentially the same as those in the Test Main program.

5 Nomenclature and Units

5.1 Station Designation

The station definition used in the program follows the international standard for performance computer programs. This standard has been published by the Society of Automotive Engineers SAE as ARP 755C.



The thermodynamic station names are defined as follows:

```
0       ambient
1       aircraft-engine interface
2       first compressor inlet

3       last compressor exit, cold side heat exchanger inlet
31      burner inlet

4       burner exit
41      first turbine stator exit = rotor inlet

5       turbine exit after addition of cooling air

6       jet pipe inlet, reheat entry

8       nozzle throat
9       nozzle exit (convergent-divergent nozzle only)
```

5.2 Units

The functions and procedures in the DLL employ SI units.

Altitude	m
Temperature	K
Pressure	kPa
Mass Flow	kg/s
Shaft Power	kW
Thrust	kN
SFC	g/(kN s)
Velocity, Spec.Thrust	m/s
Area	m²

6 Engine Program Performance Options

6.1 Engine Model File

The Engine Model File that is read during the initialization of the DLL must have been be created with GasTurb 12. The following restrictions apply:

- SI units must be selected when writing the Engine Model File
- Both rel N for PLA = 0% and rel N for PLA = 100% must be set to reasonable values. The input for these two quantities is found on the Transient Input Page in the Off-Design Input window of GasTurb 12.
- Steady state limiters must be switched on, both min and max limiters must be defined.
- If transient limiters are not constant, then the respective iteration must be defined. The input of this iteration and the required composed values is selectable from the transient input window.
- An intake map must be read from file before writing the Engine Model File from within GasTurb 12. This intake map, however, needs not necessarily be employed in the calculation.
- SMode must be set to 1.

6.1.1 Steady State Limiters

Limiters can be single valued or follow a schedule. How to employ control schedules is described in the GasTurb 12 help system and the manual.

Besides the pre-defined limiters up to three composed values can be employed as additional limiters. Note that drop-down lists with composed values (on the bottom left side of the limiter input page in GasTurb 12) will appear only if at least one composed value is defined.

In the Engine Model File delivered as an example for the Turbojet Deck application the idle spool speed is a function of altitude:

N_{Idle}=60+0.002*Altitude

The first composed value for steady state off-design operation is defined as

cp_val1 = XN_HPC*100/(60+0,002*alt)

This composed value is employed as a Min Limiter with the min value of 1.0

6.1.2 Transient Limiters

During transient operation with the GasTurb 12 control system active all the steady state limiters are activated as set in the Engine Model File. Additionally the transient limiters like dN/dt_{min} and dN/dt_{max}, for example, are active.

If you want dN/dt_{max} make a function of spool speed, for example, then you must employ an additional iteration combined with a composed value. The definitions of the composed value for transient operation and the iteration can be accessed from the menu in the transient window of GasTurb 12.

In the Engine Model File delivered as an example for the Turbojet Deck application dN/dt_{max} is a function of spool speed. The first composed value for transient operation is defined as

cp_val1 = 0.2 - 0.15*XN_HPC

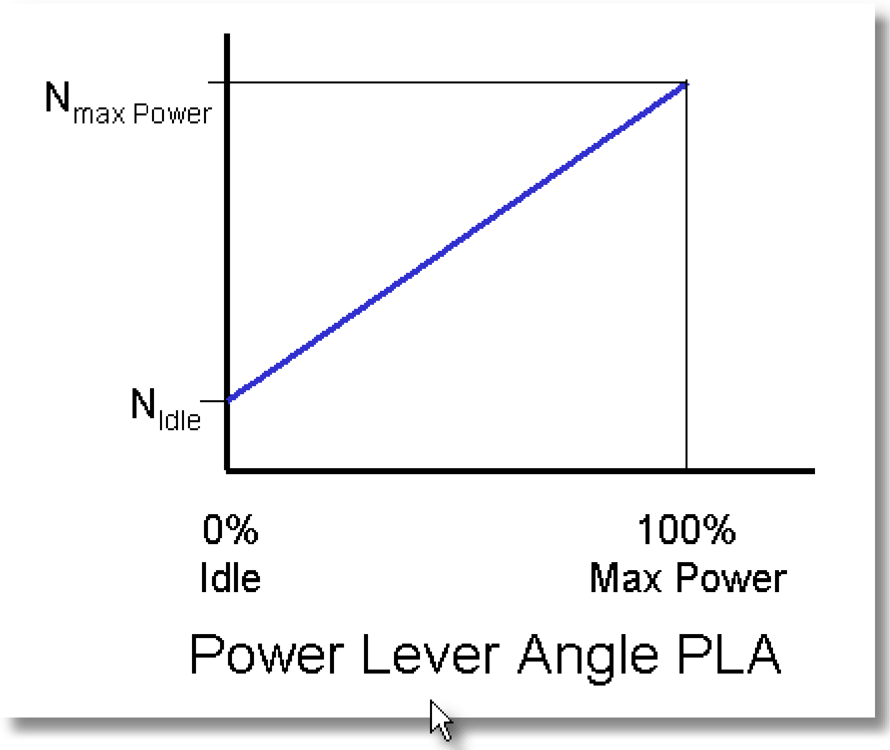
The input value for dN/dt_{max} is iterated in such a way that it equals cp_val1.

For running the simulation with modified limiter settings a new Engine Model File must be created.

6.2 Power Lever Angle

The power level selection is controlled by the input value for the Power Code ZPC. If ZPC is 0, then the Power Lever Angle input ZPLA will be used. However, any valid Rating Code ZRC will overwrite the ZPLA input.

In the Turbojet Deck the power lever angle is linearly connected with the spool speed. $N_{max\ Power}$ is equal to rel N for PLA = 100% as defined on the Transient Input Page of GasTurb 12 and N_{Idle} corresponds to rel N for PLA = 0%.



6.3 Power Code

The following Power Codes are defined:

PC = 50	Maximum
PC = 20	Idle
PC = 0	Power Lever Angle input is active, however, any valid Rating Code input ZRC overrules the Power Lever Angle input
PC = -1	run to net thrust ZFN (control system active)
PC = -2	run to fuel flow ZWF (control system active, except fuel flow schedule)
PC = -3	run to spool speed ZXNRPM (control system active)
PC = -11	run to net thrust ZFN (control system inactive)
PC = -12	run to net fuel flow ZWF (control system inactive)
PC = -13	run to spool speed ZXNRPM (control system inactive)

6.4 Rating Code

There are two valid Rating Codes defined:

1. Rating code ZRC = 50 selects maximum power

2. ZRC = 20 selects idle.

7 Input/Output

The input and output data are arranged in four groups that correspond with the COMMON blocks FIXIN, VARIN, FIXOUT and VAROUT as defined in AS681.

7.1 FIXIN

FIXIN properties are as defined in AS681. Some of them are not applicable, some of them are not used in the Turbojet Deck. Note that all data that are transferred to the functions and procedures in the DLL are of the type double.

FIXIN:

NIN		not used
NOUT		not used
IND		1,001
TITLE		Turbojet
CASE		1
ZALT	[m]	0
ZDTAMB	[K]	10
ZDT1A		not used
ZERM1A		0,99
ZPWXH	[kW]	0
ZPAMB	[kPa]	0
ZPC		0
ZPLA		90
ZP1A		0
ZRC		0
SERAM		2
SIM		1
ZTAMB		not used
ZT1A	[K]	0
ZWB3	[kg/s]	0
ZWB3Q		0,01

ZXM		0
ZERAM1		n/a
ZERM11		n/a
--		not used
--		not used
--		not used
--		not used
SDIST		not used
FYPH		not used
FYSH		not used
ZPWSD		n/a
ZTIME	[s]	0
TIMEF1		not used
TIMEF2		not used
TIMEO		not used
ZTIMET		not used
ZXJPTL		n/a
ZXNSD		n/a
ZTRQSD		n/a
SWIND		not used

There are two inlet modes selectable with the switch SIM:

SIM	1	ZALT, ZDTAMB, ZXM
	2	ZT1A, ZP1A, ZPAMB

There are three options offered for the ram pressure recovery selection switch SERAM:

SERAM	1	subsonic: ZERAM (as SERAM=2) supersonic: ZERAM*{1-0.075*(XM-1)$^{1.35}$}
	2	ZERAM
	3	ram recovery from the intake map

7.1.1 FIXIN Parameter Definition

The SAE Aerospace Standard AS681G provides a method for the presentation of results from computer programs using FORTRAN 77.

The fixed sequence list of the parameters in the fixed input labeled common (FIXIN),and the identity of these parameters (with typical nomenclature consistent with ARP755) are as follows:

1	NIN	Input file number (INTEGER)
2	NOUT	Output file number (INTEGER)
3	IND	Engine program indicator (INTEGER)
4	TITLE (18)	User title: - dimension 18 (HOLLERITH)
5	CASE	Numerical case identification
6	ALT	Geopotential pressure altitude
7	ZDTAMB	Ambient temperature minus standard atmospheric temperature
8	ZDT1A	Temperature to be added to T1A
9	ZERM1A	Ram pressure recovery at station 1A
10	ZPWXH	Customer high pressure rotor power extraction
11	ZPAMB	Ambient pressure
12	ZPC	Power code
13	ZPLA	Power lever angle
14	ZP1A	Engine inlet total pressure at station 1A
15	ZRC	Rating code
16	SERAM	Ram pressure recovery selection Average Options SERAM = 1, Selects specified ram pressure recovery SERAM = 2, Selects input value of ram pressure recovery SERAM = 3, Selects ram pressure recovery from user supplied subroutine (ERAMX)

		Differentiated Options SERAM = 4, Selects input values of primary and secondary ram pressure recovery SERAM = 5, Selects input value of primary stream ram pressure recovery and calls user supplied subroutine (ERAMX) for secondary stream ram pressure recovery SERAM = 6, Selects primary and secondary stream ram pressure recoveries from user supplied subroutine (ERAMX)
17	SIM	Inlet mode selection SIM = 1, Selects altitude and Mach number SIM = 2, Selects pressure and temperatures SIM = Other than 1 or 2 coordinated between user and supplier
18	ZTAMB	Ambient temperature
19	ZT1A	Engine inlet total temperature at station 1A
20	ZWB3	High pressure compressor discharge bleed flow rate
21	ZWB3Q	High pressure compressor bleed flow ratio (discharge over component inlet)
22	ZXM	Free stream Mach number
23	ZERAM1	Primary stream ram pressure recovery
24	ZERM11	Secondary stream ram pressure recovery
25	--	Reserved for historical consistency
26	--	Reserved for historical consistency
27	--	Reserved for historical consistency
28	--	Reserved for historical consistency
29	SDIST	Inlet pressure and temperature distortion selection
30	FYPH	Primary maximum response frequency
31	FYSH	Secondary maximum response frequency
32	ZPWSD	Specified shaft power
33	ZTIME	Time from start of transient case
34	TIMEF1	Time at which frequency is changed to FYSH
35	ZIMEF2	Time at which frequency is changed to FYPH
36	TIMEO	Output time interval
37	ZTIMET	Termination time of transient case
38	ZXJPTL	Polar moment of inertia of power turbine load
39	ZXNSD	Specified shaft rotational speed

40	ZTRQSD	Specified shaft torque
41	SWIND	Windmilling selection

7.2 VARIN

SEST	0	begin the iteration with the values from previous point
	1	begin the iteration with ZBTAC, ZXNH, ZBTAT, ZDTRC
ZBTAC		beta value in the compressor map
ZRXNH		relative spool speed
ZBTAT		beta value in the turbine map
ZDTRC		temperature increase due to recirculating bleed air
ZFN		specified net thrust
ZWF		specified fuel flow
ZXNRPM		specified spool speed in RPM
STRANS	1	Transient with ZPLA = f(ZTIME) input, the GasTurb control system is active
	2	Transient with ZWF = f(ZTIME) input, the GasTurb control system is inactive
	3	Transient with ZXNRPM = f(ZTIME) input,the GasTurb control system is inactive
ZCTRCP		proportional constant of the GasTurb PID controller
ZCTRCD		differential constant of the GasTurb PID controller
ZCTRCI		integral constant of the GasTurb PID controller

7.3 FIXOUT

FIXOUT properties are as defined in AS681. Some of them are not applicable, some of them are not used in the Turbojet Deck. Note that all data that are transferred from the functions and procedures in the DLL are of the type double.

FIXOUT:

CLASS		not used
IDENT		not used
NSI		0
AE8	[m²]	0,0759551
AE18		n/a
ANGBT		not used
FRAM	[kN]	0
FG	[kN]	25,4526
FGI	[kN]	not used
FG19	[kN]	n/a
FGI19	[kN]	n/a
FHV	[MJ/kg]	43,124
FN	[kN]	25,4526
PB3	[kPa]	1203,74
P7	[kPa]	343,983
P17		n/a
SFC	[g/(kN*s)]	24,9687
--		not used
TB3		651,127
TC		not used
T7	[K]	1082,75
T17	[K]	n/a
WFE	[kg/s]	0,635519
WFT	[kg/s]	0,635519
W1A	[kg/s]	31,1442
W7	[kg/s]	31,4683
W17		n/a
W2	[kg/s]	31,1442
XNH	[RPM]	14283,9
XNI		n/a
XNL		n/a
XNSD		n/a
ALT	[m]	0
ERAM1A		not used

ERAM1A		not used
PAMB	[kPa]	101,325
PLA		90
P1A	[kPa]	100,312
TAMB	[K]	298,15
T1A	[K]	298,15
XM		0
SML		n/a
SMI		n/a
SMH		32,8606
--		not used
--		not used
PWSD		n/a
TIME		0
TRQSD		n/a
ERAM1		0,99
ERAM11		n/a
--		not used
--		not used
--		not used
--		not used
DTAMB	[K]	0
DT1A		not used
PC		0
RC		0
WB3	[kg/s]	0,311442
WB3Q		0,01
PWXH	[kW]	0

7.3.1 FIXOUT Parameter Definition

The SAE Aerospace Standard AS681G provides a method for the presentation of results from computer programs using FORTRAN 77.

The fixed sequence list of the parameters in the fixed output labeled common (FIXOUT),and the identity of these parameters (with typical nomenclature consistent with ARP755) are as follows:

1	CLASS (6)	Engine program security classification - Dimension 6 (HOLLERITH)
2	IDENT (36)	Engine program titles - Dimension 36 (HOLLERITH)

3	NSI (10)	Numerical Status Indicator - Dimension 10 (INTEGER)
4	AE8	Primary exhaust nozzle throat effective area
5	AE18	Bypass exhaust nozzle throat effective area
6	ANGBT	Boat-tail angle
7	FRAM	Ram drag
8	FG	Gross thrust
9	FGI	Ideal gross thrust
10	FG19	Bypass stream gross thrust
11	FGI19	Bypass stream ideal gross thrust
12	FHV	Fuel lower heating value
13	FN	Net thrust
14	PB3	High pressure compressor discharge bleed flow total pressure
15	P7	Primary exhaust flow total pressure
16	P17	Bypass exhaust flow total pressure
17	SFC	Specific fuel consumption
18	--	Reserved for historical consistency
19	TB3	High pressure compressor discharge bleed flow total temperature
20	TC	Control temperature (cockpit display)
21	T7	Primary exhaust flow total temperature
22	T17	Bypass exhaust flow total temperature
23	WFE	Engine fuel flow rate
24	WFT	Total fuel flow rate
25	W1A	Engine inlet flow rate at station 1A
26	W7	Primary exhaust flow rate
27	W17	Bypass exhaust flow rate
28	W2_	High pressure compressor inlet flow rate (The full number representing the relevant station designation, e.g., W21, W215, W2A, will be defined by the program supplier.)
29	XNH	High pressure rotor rotational speed
30	XNI	Intermediate pressure rotor rotational speed
31	XNL	Low pressure rotor rotational speed

32	XNSD	Delivered shaft rotational speed
33	ALT	Geopotential pressure altitude
34	ERAM1A	Ram pressure recovery at station 1A
35	PAMB	Ambient pressure
36	PLA	Power lever angle
37	P1A	Engine inlet total pressure at station 1A
38	TAMB	Ambient temperature
39	T1A	Engine inlet total temperature at station 1A
40	XM	Free stream Mach number
41	SML	Low Pressure Compressor Surge Margin
42	SMI	Intermediate Pressure Compressor Surge Margin
43	SMH	High Pressure Compressor Surge Margin
44	--	Reserved for historical consistency
45	--	Reserved for historical consistency
46	PWSD	Delivered shaft power
47	TIME	Output Time, from start of transient case
48	TRQSD	Delivered shaft torque
49	ERAM1	Primary stream ram pressure recover
50	ERAM11	Secondary stream ram pressure recover
51	--	Reserved for historical consistency
52	--	Reserved for historical consistency
53	--	Reserved for historical consistency
54	--	Reserved for historical consistency
55	DTAMB	Ambient temperature minus standard atmosphere temperature
56	DT1A	Temperature added to T1A
57	PC	Power code
58	RC	Rating code
59	WB3	High pressure compressor discharge total bleed flow rate (Resultant from combined inputs no 20 and 21 of FIXIN)
60	WB3Q	High pressure compressor total bleed flow ratio (discharge over component inlet)

		(Resultant from combined inputs no 20 and 21 of FIXIN)
61	PWXH	Customer high pressure rotor power extraction

7.4 VAROUT

humid	relative humidity [%]
T2	compressor inlet temperature
T3	compressor exit temperature
T4	burner exit temperature
T41	turbine stator exit temperature
T5	turbine exit temperature
P3	compressor exit) pressure
PS3	compressor exit static pressure
P5	turbine exit pressure
NHDOT	spool speed change, % per second
FAR4	burner fuel-air-ratio
LIMCD	limiter code
BTAC	beta value in the compressor map
RXNH	relative spool speed
BTAT	beta value in the turbine map
DTRC	temperature increase due to recirculating bleed air

8 Program Messages

8.1 Numerical Status Indicator NSI

The following Numerical Status Indicator values are defined:

0	Valid result
600	A component map was extrapolated
1600	Surge margin < 0
9100	Calculation did not converge

9199	Severe computing problem
9201	SIM must be 1 or 2
9202	ZP1A, ZT1A or ZPAMB=0 while SIM=2
9203	SIM=2 can not be combined with SERAM=3
9204	SERAM must be 1, 2 or 3
9210	ZRC not defined
9290	Power Lever Angle PLA definition error
9291	Engine model error: SMode must be equal to 1
9292	STRANS must be 1, 2 or 3 during transient operation
9293	TIME >= ZTIME is not permitted

8.2 Steady State Limiter Codes

During steady state simulations the following limiter codes are used:

-5	cp_val_min3	value of the third cp_val min limiter
-4	cp_val_min2	value of the second cp_val min limiter
-3	cp_val_min1	value of the first cp_val min limiter
-2	WF_min	min fuel flow
-1	NH_min	min gas generator spool speed
0		operation within limits or no limiters activated
1	NL_max	max low-pressure spool speed
2	NLR_max	max corrected low-pressure spool speed
3	NH_max	max high-pressure spool speed
4	NHR_max	max corrected high-pressure spool speed
5	T3_max	max burner inlet temperature
6	P3_max	max burner inlet pressure
7	T41_max	max stator outlet temperature (SOT)
8	T45_max	max low-pressure turbine inlet temperature
9	T5_max	max turbine exit temperature
10	TRQ_max	max torque
11	cp_val_max1	value of the first cp_val max limiter

12	cp_val_max2	value of the second cp_val max limiter
13	cp_val_max3	value of the third cp_val max limiter

8.3 Transient Limiter Codes

During transient simulations the limiter code LIMCD in VAROUT can have the following values:

0		control system switched off
1	Control	operation within limits
2	N	max spool speed
3	N,corr	max corrected spool speed
4	T3	max burner inlet temperature
5	P3	max burner inlet pressure
6	T41	max stator outlet temperature (SOT)
7	T5	max turbine exit temperature
8	cp_val_max1	max composed value 1
9	cp_val_max2	max composed value 2
10	cp_val_max3	max composed value 3
11	N_dot_max	max dN/dt (acceleration)
12	far max	max fuel-air-ratio (acceleration)
13	WF/P3 max	max WF/P3 (acceleration)
14	WF max	max fuel flow
15	N_dot_min	min dN/dt (deceleration)
16	far_min	min fuel-air-ratio (deceleration)
17	WF/P3 min	min WF/P3 (deceleration)
18	Nmin	min spool speed
19	WF min	min fuel flow
20	cp_val_min1	min composed value 1
21	cp_val_min2	min composed value 2
22	cp_val_min3	min composed value 3

8.4 About Convergence Problems

Any off-design gas turbine performance simulation program requires iteration. That means that the values of some variables must be estimated at the beginning of the calculation. Corresponding with the number of iteration variables there is an equal number of conditions within the mathematical model of the gas turbine. While the iteration variables do not have their correct value, then some or all of the conditions are not fulfilled. A sophisticated algorithm varies the variables iteratively in such a way that all the conditions are fulfilled when the calculation is finished.

Sometimes the iteration fails to converge which is indicated by NSI=9100. Non-convergence can have many reasons: sometimes one or the other of the normal input properties are unreasonable, sometimes the start values of the iteration variables are far away from those of the solution, sometimes the solution requires one or more components operating far outside of their respective component maps.

In this computer deck the output values of the iteration variables are BTAC, RXNH, BTAT and DTRC in the VAROUT group. While SEST is zero, these values are employed as estimates for the next point to be calculated. If a point has not converged, then most probably the values of BTAC, RXNH, BTAT and DTRC are unreasonable and not suited as estimate for the next case to be calculated. For recovering from this situation, SEST can be set to 1 which makes the iteration begin with the values ZBTAC, ZXNH, ZBTAT, ZDTRC from the VARIN group.

If the iteration fails to converge because the operating conditions between two steady state points are very different - an idle case followed by a max rating case, for example - then the problem can be avoided eventually by introducing a few intermediate rating steps.

Convergence problems that are not understood can be examined with GasTurb 12. In this program there are many more diagnostic options available than in this computer deck.

If non of the advice given above helps then it might be that no solution exists. This can be the case for excessive power or bleed off-take, for example.

If in transient simulations a convergence problem shows up while one of the input properties changes significantly in a very short time, then the time step might be too big. This is similar to the case when the spool speed input (while STRANS=3) implies excessive Ndot (dN/dt) values.

If during a transient simulation the iteration converges after having failed at one or a few prior time steps, then the convergence problem can mostly be ignored.

9 Test Cases

9.1 Cycle Reference Point

During initialization of the DLL the GasTurb cycle reference point is written to the input (i.e. FIXIN and VARIN) and the output (FIXOUT and VAROUT) groups.

9.2 Steady State Off-Design

The performance point to be calculated is defined by the data given in FIXIN and VARIN. For a steady state point ZTIME must be set to zero.

9.3 Transient

A transient simulation is performed if the FIXIN property ZTIME has a positive value greater than the FIXOUT property TIME from the previously calculated point.

Three examples are selectable in the test main program respectively in the Excel sheet:

- a 10% step increase in fuel flow which demonstrates the fuel flow input option (STRANS=2)
- a PLA maneuver with a slam deceleration followed by a slam acceleration
- a spool speed input as a function of time

10 Identification and Revision Procedure

The version of the DLL can be read by calling the function GetDLLVersion.

The responsibility for the data is with the provider of the Engine Model File.

11 References

[1] SAE
AEROSPACE STANDARD AS681 Rev. G
1996

[2] J. Kurzke
GasTurb 12 User Manual
2012

Index