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VOLUME III

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CONTRACT AF 61 (052) -750

EXPERIMENTAL AND DESIGN STUDIES
TURBO - RAMJET COMBINATION ENGIN

FINAL REPORT

DATA

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VOLUME 3

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AFAPL-TR-66-34
Volume III

EXPERIMENTAL AND DESIGN STUDIES FOR TURBO-RAMJET COMBINATION ENGINE
Volume III - Data

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Technical Report AFAPL-TR-66-34, Volume III
January 1966

Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

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FOREWORD

This report was prepared by Nord Aviation, France under Contract AF 61(052)-750 initiated under Project No. 3012, Task No. 301203. The work was administered under the direction of the Air Force Aero Propulsion Laboratory, Turbine Engine Division, with Isak J. Gershon as project engineer.

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained herein. This report has been reviewed and is published only for the exchange and stimulation of ideas.

E. C. Simpson

E. C. Simpson
Chief, Turbine Engine Division
Air Force Aero Propulsion Laboratory

EXPERIMENTAL AND DESIGN STUDIES

FOR TURBO-RAMJET COMBINATION ENGINE

Volume 3 - DATA

-:-

S U M M A R Y

In this document, we have produced all the data necessary for the calculations relating to the performance characteristics of the turbofan-ramjet combination engine.

- In Vol. 3.1, we have brought together the geometric and thermodynamic characteristics of the SNECMA TF 106 turbofan : TURBOFAN DATA (5150/NIOBE IV/32/Z).

- In Vol. 3.2, we have given the numerical values of the various parameters, coefficients and functions defining the efficiencies of the different parts of the engine, as well as the geometrical characteristics peculiar to the combination engine : GENERAL DATA (5151/NIOBE IV/33/Z).

AF 61 (052)-750

5150/NIOBE IV/32/Z

October 1965

FINAL REPORT

EXPERIMENTAL AND DESIGN STUDIES FOR TURBO-RAMJET COMBINATION ENGINE

Volume 3.1 - TURBOFAN DATA

NORD - AVIATION

DEPARTEMENT "PROPULSEURS"

PARIS (CHATILLON), FRANCE

The research reported in this document has been sponsored by the AERONAUTICAL SYSTEMS DIVISION, AFSC, through the European Office of Aerospace Research, United States Air Force.

SUMMARY

In this document, we have brought together the geometric and thermodynamic characteristics of turbofan SNECMA TF 106, necessary for calculating the cycle and performance characteristics of the turbofan-ramjet combination powerplant built around this turbofan.

In addition we have given the comparative values of the sea level static performance characteristics provided by the manufacturer and calculated from the thermodynamic data.

.../..

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2 - GEOMETRICAL DATA

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4 - SEA LEVEL STATIC CHARACTERISTICS

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6 - COMBUSTION EFFICIENCY

7 - TABLES OF THERMODYNAMIC CHARACTERISTICS

LIST OF FIGURES

Fig. 1 - Fan-compressor characteristics

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SYMBOLS

General Symbols

A	Cross-sectional area
P	Total pressure
T	Total temperature
D	Turbofan air flow
p_{oo}	Static pressure at sea level
t_{oo}	Static temperature at sea level
β	By-pass ratio
q_{Ti}	Injected fuel flow
q_{Tb}	Burned fuel flow
$d_{T1} = \frac{D\sqrt{T_1}}{P_1}$	Turbofan inlet corrected air flow
η'_T	Combustion efficiency

Superscripts

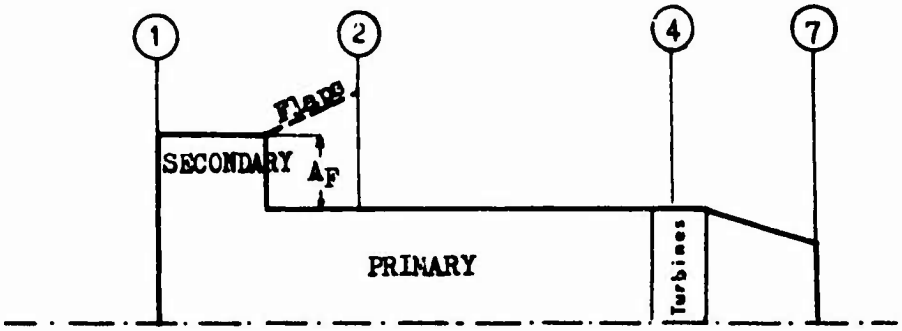
Indicates primary flow parameters

Subscripts

F	Refers to secondary flow
T	Refers to the turbofan total flow, or to the turbofan as a whole

.../..

Numerical subscripts refer to various stations as indicated in the diagram below :



1 - INTRODUCTION

The calculation of the cycle and performance characteristics of a turbofan-ramjet combination powerplant built around a turbofan requires that the geometrical and thermodynamic characteristics of the latter be known.

In this document, we have collected the data related to the SNECMA TF 106 turbofan which is used in the present investigation.

The thermodynamic data have been provided to us by the manufacturer, in the form of three-parameter sets of curves, for the following engine inlet temperatures :

T_1 = 260 °K	(468 °R)
T_1 = 288 °K	(518 °R)
T_1 = 324 °K	(583 °R)
T_1 = 360 °K	(648 °R)
T_1 = 390 °K	(702 °R)
T_1 = 420 °K	(756 °R)
T_1 = 450 °K	(810 °R)
T_1 = 550 °K	(990 °R)

with the turbine inlet temperature being maximum.

2 - GEOMETRICAL DATA

The SNECMA TF 106 turbofan, which has been selected for the present research, is an axial, twin spool turbojet, with mixed flows, and featuring a moderate by-pass ratio.

.../..

The nine-stage low pressure compressor includes three fan stages, and is driven by a three-stage turbine.

The seven-stage high pressure compressor is driven by a single-stage turbine.

The overall pressure ratio is approximately 16/1 , the fan pressure ratio is equal to 2.1/1 and the by-pass ratio is 1.2 at sea level static conditions.

The major geometrical characteristics are the following :

Length (from engine inlet to turbine flange)	90 in
External cross-section area at the level of the turbine flange, A'_4	5.1 sq.ft
Engine inlet sectional area, A_{T1}	7.1 sq.ft
Secondary flow exit cross-sectional area, A_F	2.1 sq.ft
Primary flow exit cross-sectional area (issuing from the previous investigation, Contract AF 61 (052)-670, A'_7	4 sq.ft
Weight, excluding the variable convergent exit nozzle ..	3,100 lb
Weight of the variable convergent exit nozzle	400 lb
Total dry weight	3,500 lb

3 - THERMODYNAMIC DATA

All thermodynamic characteristics are given for maximum rating, that is for maximum turbine inlet temperature.

In the "short nozzle" configuration, the primary flow exhaust nozzle opens into the internal part of the engine, within a high static pressure zone, and is generally not sonic. The secondary outlet, equipped with the movable-flapped mixer, has a variable cross-section area.

.../..

Thus the turbofan is equivalent to a conventional turbofan with variable sonic exits, which means that its thermodynamic characteristics are expressed in terms of three independent parameters, for example the two corrected exit flows and the fuel flow.

The fuel flow determines the ratio TIT / T_1 between turbine inlet temperature, TIT, and engine inlet temperature, T_1. Since the characteristics are given for maximum rating, temperature TIT is fixed, and the first parameter adopted by SNECMA is temperature T_1.

The other two parameters selected are

- the corrected air flow at the engine inlet :

$$\mathcal{D}_1 = D \frac{\sqrt{T_1 / t_{oo}}}{P_1 / p_{oo}}$$

- parameter $\mathfrak{M}_\ell$ which is defined as follows :

$$\mathfrak{M}_\ell = \frac{P_{F2} / P_1}{\mathcal{D}_1}$$

The systems of curves provided by SNECMA, for each value of temperature T_1, in terms of the corrected flow $\mathcal{D}_1$, and with $\mathfrak{M}_\ell$ as a parameter, give :

- the by-pass ratio, β = secondary flow / primary flow
- ratio T_{F2} / T_1, characterising the exit total temperature of the secondary flow
- ratio P'_7 / P_1, characterizing the exit total pressure of the primary flow
- ratio T'_7 / T_1, characterizing the exit total temperature of the primary flow.

.../..

SNECMA has also supplied us with plates showing, in terms of the same parameters as above, the corrected r.p.m. of the L.P. rotor, the corrected fuel flow, the exit total pressure and temperature ratios of the H.P. compressor, and the corrected r.p.m. of the H.P. rotor. The latter three plates make it possible to determine the utilization zones of the former.

4 - SEA LEVEL STATIC CHARACTERISTICS

These, extracted from the manufacturer's literature, are the following :

Air flow	250 lb/sec
Thrust	11,250 lb
Specific fuel consumption	0.597 lb/lb.hr
Specific thrust	45 sec

It should be noticed that the results obtained from thermodynamic data (see Vol. 4.1 - PARAMETRIC CALCULATIONS OF PERFORMANCE CHARACTERISTICS) are somewhat different from the above values. We find :

Air flow	235 lb/sec
Thrust	11,500 lb
Specific fuel consumption	0.585 lb/lb.hr

These differences result from a shifting of the operating point, due,on the one hand, to the head losses in the annular duct, and, on the other hand, to the primary exit cross-sectional area, which are different from SNECMA's.

.../..

The law of the annular duct head losses, issuing from the mixer tests performed under cover of the previous contract AF 61 (052)-670, is better than SNECMA's.

The primary exit cross-sectional area chosen (4sq.ft) is smaller (for SNECMA : 5 sq.ft). The lowering of the exit sectional area makes up partly for the effect of the head losses diminution. However, the influence of the latter is preponderant.

5 - FAN-COMPRESSOR CHARACTERISTICS

From the thermodynamic data of the TF 106 engine we have deduced the characteristics of the fan compressor : fan compressure ratio in terms of Φ_1 (Fig. 1).

In addition we have plotted in this figure the corrected r.p.m.'s of the fan rotor : $N_1 / \sqrt{T_1 / t_{oo}}$

6 - COMBUSTION EFFICIENCY

The manufacturer has not supplied us with the value of the combustion efficiency.

We have evaluated it

- from the curves of corrected fuel flow, as concerns the injected fuel,
- from the overall energetic balance, as concerns the burned fuel ;

$$\eta'_T = \frac{q_{Tb}}{q_{Ti}}$$

For all the performance characteristics calculations, we have made use of a constant value for the combustion efficiency :

$$\eta'_T = 0.97$$

.../..

7 - TABLES OF THERMODYNAMIC CHARACTERISTICS

Further on we exhibit the tables of thermodynamic data, derived from the manufacturer's curve systems, and used for the performance characteristics calculation.

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 260.0 °K

$\eta 1$ = 0.018 sec/kg

$\frac{dT1}{sq.ft\ \sqrt{°R}/s}$	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.54204	1.2760	2.7060	3.4740	1.9260	1.2650
2.58956	1.2720	2.6520	3.4430	1.9620	1.2810
2.63707	1.2680	2.5800	3.4060	1.9980	1.2985
2.66083	1.2660	2.5300	3.3840	2.0160	1.3080
2.68459	1.2650	2.4700	3.3590	2.0340	1.3178
2.70834	1.2690	2.3950	3.3300	2.0520	1.3280
2.73210	1.2800	2.3000	3.2960	2.0700	1.3400
2.75586	1.3050	2.1740	3.2560	2.0880	1.3520
2.76774	1.3280	2.0900	3.2320	2.0970	1.3580
2.77962	1.3650	1.9800	3.2040	2.1060	1.3650
2.78674	1.4250	1.8700	3.1750	2.1114	1.3700
2.79149	1.6600	1.5450	3.1160	2.1150	1.3727

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 260.0 °K

$\mathfrak{M}1 = 0.019$ sec/kg

dT1 sq.ft $\sqrt{°R}/a$	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.49453	1.2325	2.7340	3.4820	1.9950	1.2640
2.58956	1.2207	2.6520	3.4210	2.0710	1.2910
2.66083	1.2090	2.5570	3.3700	2.1280	1.3140
2.68459	1.2050	2.5150	3.3500	2.1470	1.3230
2.70834	1.2015	2.4630	3.3290	2.1660	1.3320
2.73210	1.2000	2.4000	3.3040	2.1850	1.3420
2.75586	1.2030	2.3170	3.2740	2.2040	1.3540
2.76774	1.2100	2.2530	3.2520	2.2135	1.3600
2.77962	1.2320	2.1430	3.2200	2.2230	1.3670
2.78674	1.2700	2.0200	3.1890	2.2287	1.3710
2.79149	1.3750	1.8300	3.1540	2.2325	1.3740

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 260.0 ° K

$\eta 1$ = 0.021 sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.42325	1.1350	2.7150	3.4640	2.1420	1.2950
2.51828	1.1200	2.6710	3.4140	2.2260	1.3160
2.58956	1.1050	2.6300	3.3750	2.2890	1.3320
2.63707	1.0940	2.5900	3.3460	2.3310	1.3430
2.66083	1.0880	2.5700	3.3310	2.3520	1.3490
2.68459	1.0810	2.5400	3.3150	2.3730	1.3550
2.70834	1.0725	2.5050	3.2960	2.3940	1.3620
2.73210	1.0625	2.4600	3.2740	2.4150	1.3695
2.74398	1.0568	2.4300	3.2600	2.4255	1.3735
2.75586	1.0500	2.3850	3.2400	2.4360	1.3780
2.77249	1.0375	2.2800	3.1980	2.4507	1.3845
2.77962	1.0400	2.2000	3.1730	2.4570	1.3880
2.78437	1.0575	2.1140	3.1510	2.4612	1.3905
2.79149	1.2450	1.8800	3.1000	2.4675	1.3945

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 260.0 °K

$\eta_1 = 0.023$ sec/kg

dT1 sq.ft$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.32822	1.0160	2.7200	3.4515	2.2540	1.3340
2.42325	1.0010	2.6780	3.4000	2.3460	1.3540
2.51828	0.9840	2.6270	3.3500	2.4380	1.3760
2.56580	0.9740	2.5960	3.3240	2.4840	1.3870
2.61331	0.9630	2.5600	3.2965	2.5300	1.4000
2.63707	0.9550	2.5390	3.2820	2.5530	1.4070
2.66083	0.9460	2.5140	3.2655	2.5760	1.4140
2.68459	0.9340	2.4860	3.2475	2.5990	1.4210
2.70834	0.9190	2.4560	3.2270	2.6220	1.4290
2.73210	0.8970	2.4190	3.2020	2.6450	1.4360
2.75586	0.8690	2.3610	3.1690	2.6680	1.4420
2.76774	0.8540	2.3200	3.1470	2.6790	1.4450
2.77962	0.8360	2.2520	3.1180	2.6910	1.4480
2.79149	0.8200	2.1000	3.0760	2.7020	1.4510

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 260 ° K

L.P. Surge line

dT1 sq.ft $\sqrt{°R}/s$	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.30447	0.9720	2.7180	3.4450	2.2900	1.3490
2.37574	0.9660	2.6900	3.4070	2.3600	1.3630
2.47077	0.9540	2.6470	3.3600	2.4480	1.3820
2.56580	0.9410	2.5900	3.3080	2.5290	1.4020
2.61331	0.9340	2.5550	3.2810	2.5650	1.4120
2.66083	0.9250	2.5100	3.2540	2.6000	1.4220
2.68459	0.9200	2.4810	3.2380	2.6170	1.4280
2.70834	0.9100	2.4500	3.2220	2.6350	1.4330
2.73210	0.8920	2.4130	3.2000	2.6520	1.4380
2.75586	0.8660	2.3560	3.1680	2.6700	1.4440
2.76774	0.8520	2.3190	3.1470	2.6800	1.4470
2.77 962	0.8350	2.2600	3.1180	2.6910	1.4490
2.79149	0.8190	2.1600	3.0760	2.7020	1.4520

S N E C M A

TF 105 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 288 °K

$\eta 1 = 0.017$ sec/kg

dT1 sq.ft/$\sqrt{°R}$/sec	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.333100	1.5100	2.2550	3.1400	1.6690	1.2120
2.375520	1.4400	2.2300	3.1160	1.7000	1.2200
2.425010	1.3820	2.2020	3.0920	1.7330	1.2340
2.446220	1.3620	2.1900	3.0780	1.7500	1.2400
2.467430	1.3500	2.1700	3.0650	1.7670	1.2460
2.516920	1.3350	2.1350	3.0380	1.8000	1.2600
2.562875	1.3300	2.0900	3.0080	1.8350	1.2740
2.613000	1.3300	2.0300	2.9760	1.8700	1.2900
2.658320	1.3300	1.9450	2.9400	1.9030	1.3070
2.707810	1.3300	1.8300	2.8980	1.9370	1.3260
2.729020	1.3320	1.7450	2.8740	1.9550	1.3370
2.757300	1.3450	1.6300	2.8300	1.9720	1.3520

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 288.0 °K

$\mathcal{M}1 = 0.019$ sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.269470	1.4150	2.2550	3.1350	1.8150	1.2280
2.280075	1.3700	2.2340	3.1300	1.8250	1.2300
2.304820	1.3350	2.2320	3.1280	1.8430	1.2320
2.326030	1.3150	2.2300	3.1080	1.8630	1.2360
2.376934	1.2900	2.2200	3.0860	1.9000	1.2450
2.494296	1.2550	2.1700	3.0260	1.9950	1.2690
2.613000	1.2330	2.0700	2.9600	2.0900	1.2980
2.658320	1.2230	2.0150	2.9280	2.1300	1.3130
2.707810	1.2100	1.9100	2.8900	2.1680	1.3320
2.729020	1.2080	1.8800	2.8660	2.1850	1.3420
2.757300	1.2150	1.8000	2.8300	2.2050	1.3540
2.774975	1.2550	1.6000	2.7000	2.2230	1.3580

S N E C M A

TF 106 - TURBOFAN ENGINE

MaximumRated Turbine Inlet Temperature

Engine inlet temperature : 288.0 °K

$\eta 1$ - 0.021 sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.174000	1.3000	2.2150	3.1300	1.9215	1.2540
2.234120	1.2200	2.2000	3.0990	1.9740	1.2660
2.283610	1.1950	2.1900	3.0780	2.0160	1.2730
2.326030	1.1800	2.1800	3.057	2.0580	1.2800
2.375520	1.1650	2.1670	3.0350	2.1000	1.2880
2.492175	1.1450	2.1150	2.9800	2.2050	1.3100
2.610951	1.1150	2.0380	2.9170	2.3100	1.3360
2.659734	1.1000	1.9950	2.8900	2.3520	1.3480
2.707810	1.0800	1.9350	2.8570	2.3940	1.3620
2.729020	1.0650	1.8950	2.8330	2.4150	1.3690
2.753765	1.0470	1.8350	2.7980	2.4360	1.3770

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 288.0 °K

$\eta 1 = 0.023$ sec/kg

$\delta T1$ sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.06091	1.1850	2.2000	3.1320	1.9950	1.2840
2.08918	1.1200	2.1980	3.1060	2.0230	1.2900
2.13514	1.0900	2.1920	3.0850	2.0700	1.3000
2.23412	1.0570	2.1750	3.0420	2.1600	1.3170
2.32957	1.0350	2.1470	2.9980	2.2530	1.3350
2.42501	1.0180	2.1070	2.9520	2.3450	1.3540
2.51692	0.9950	2.0550	2.9040	2.4100	1.3760
2.61237	0.9670	1.9900	2.8520	2.5300	1.4000
2.65832	0.9480	1.9420	2.8210	2.5750	1.4120
2.70781	0.9200	1.8700	2.7830	2.6200	1.4270
2.72902	0.9000	1.8150	2.7580	2.6450	1.4340
2.75730	0.8650	1.7400	2.7220	2.6700	1.4440

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 324.0 ° K

$\eta 1 = 0.015$ sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.067975	1.7920	1.7020	2.8250	1.3050	1.1680
2.139382	1.7090	1.7090	2.7890	1.3500	1.1780
2.210789	1.6380	1.7080	2.7530	1.3950	1.1880
2.305527	1.5580	1.6930	2.7020	1.4550	1.2000
2.376934	1.5110	1.6660	2.6630	1.5000	1.2210
2.448341	1.4770	1.6190	2.6230	1.5450	1.2390
2.543079	1.4500	1.5330	2.5670	1.6050	1.2660
2.614486	1.4470	1.4450	2.5200	1.6500	1.2910
2.661855	1.4570	1.3580	2.4840	1.6800	1.3080
2.709931	1.4870	1.2360	2.4380	1.7100	1.3280
2.733262	1.5240	1.1470	2.3700	1.7250	1.3390

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 324.0 °K

$\mathfrak{M}1 = 0.017$ sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.949199	1.7930	1.7500	2.8770	1.3940	1.1540
2.043937	1.5930	1.7680	2.8310	1.4620	1.1650
2.139382	1.6020	1.7760	2.7850	1.5300	1.1780
2.210789	1.5390	1.7740	2.7490	1.5810	1.1890
2.305527	1.4690	1.7580	2.7000	1.6490	1.2060
2.376934	1.4260	1.7320	2.6620	1.7000	1.2220
2.448341	1.3920	1.6880	2.6230	1.7510	1.2390
2.543079	1.3580	1.6040	2.5670	1.8190	1.2670
2.614486	1.3380	1.5170	2.5170	1.8700	1.2910
2.685893	1.3370	1.3960	2.4540	1.9210	1.3180
2.757300	1.3890	1.1620	2.3560	1.9720	1.3500

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 324.0 °K

$\eta 1 = 0.019$ sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.901830	1.5920	1.8070	2.8670	1.5200	1.1590
1.973237	1.5460	1.7970	2.8310	1.5770	1.1730
2.067975	1.4860	1.7810	2.7830	1.6530	1.1900
2.139382	1.4430	1.7680	2.7480	1.7100	1.2020
2.210789	1.4040	1.7530	2.7130	1.7670	1.2140
2.305527	1.3540	1.7290	2.6650	1.8430	1.2290
2.376934	1.3190	1.7070	2.6310	1.9000	1.2400
2.448341	1.2890	1.6790	2.5970	1.9570	1.2530
2.543079	1.2560	1.6310	2.5530	2.0330	1.2750
2.614486	1.2360	1.5650	2.5110	2.0900	1.2950
2.685893	1.2210	1.4610	2.4580	2.1470	1.3200
2.757300	1.2120	1.2830	2.3760	2.2040	1.3510

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature
Engine inlet temperature : 324.0 °K

$\mathfrak{M}1 = 0.021$ sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.711647	1.3710	1.8570	2.8930	1.5120	1.1730
1.806738	1.3530	1.8280	2.8460	1.5960	1.1870
1.901830	1.3330	1.7990	2.8010	1.6800	1.2030
2.020606	1.3030	1.7620	2.7430	1.7850	1.2260
2.139382	1.2690	1.7260	2.6880	1.8900	1.2530
2.258158	1.2320	1.6880	2.6330	1.9950	1.2860
2.376934	1.1940	1.6460	2.5810	2.1000	1.3280
2.495710	1.1580	1.6020	2.5270	2.2050	1.3630
2.614486	1.1220	1.5160	2.4620	2.3100	1.3750
2.685893	1.0920	1.4260	2.4140	2.3730	1.3730
2.757300	1.0400	1.3110	2.3480	2.4360	1.3670

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S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 324 ° K

L. P. Surge line

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.663571	1.2360	1.8770	2.8790	1.5850	1.1940
1.783054	1.1940	1.8350	2.8130	1.7000	1.2250
1.901830	1.1530	1.7920	2.7490	1.8400	1.2530
2.020606	1.1130	1.7460	2.6860	1.9900	1.2810
2.139382	1.0740	1.6990	2.6240	2.1300	1.3080
2.258158	1.0380	1.6470	2.5670	2.2400	1.3320
2.376934	1.0020	1.5860	2.5060	2.3600	1.3550
2.495710	0.9710	1.5080	2.4440	2.4600	1.3830
2.614486	0.9430	1.3900	2.3790	2.5600	1.4160

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 360.0 °K

$\mathfrak{M}_1$ = 0.017 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.90059	1.9600	1.4550	2.5500	1.3600	1.1480
1.99087	1.8000	1.4750	2.5050	1.4246	1.1595
2.04314	1.7260	1.4800	2.4815	1.4620	1.1655
2.09065	1.6670	1.4805	2.4590	1.4960	1.1720
2.11441	1.6410	1.4795	2.4470	1.5130	1.1750
2.13817	1.6200	1.4760	2.4350	1.5300	1.1784
2.18568	1.5820	1.4635	2.4100	1.5640	1.1861
2.23319	1.5470	1.4450	2.3840	1.5980	1.1942
2.32822	1.4850	1.4005	2.3315	1.6660	1.2122
2.39950	1.4370	1.3635	2.2920	1.7170	1.2265
2.42325	1.4200	1.3475	2.2790	1.7340	1.2318
2.47077	1.3940	1.3100	2.2500	1.7680	1.2438
2.51828	1.3775	1.2655	2.2215	1.8020	1.2565
2.56580	1.3670	1.2155	2.1900	1.8360	1.2710
2.61331	1.3600	1.1510	2.1550	1.8700	1.2873
2.66083	1.3550	1.0775	2.1175	1.9040	1.3055

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 360.0 °K

$\mathfrak{M}_1$ = 0.019 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.80556	1.7500	1.5600	2.5750	1.4440	1.1480
1.89109	1.6530	1.5230	2.5225	1.5124	1.1640
1.94811	1.5950	1.5040	2.4877	1.5580	1.1740
1.99562	1.5550	1.4870	2.4600	1.5960	1.1828
2.01938	1.5375	1.4790	2.4470	1.6150	1.1870
2.04314	1.5230	1.4700	2.4345	1.6340	1.1910
2.13817	1.4760	1.4390	2.3900	1.7100	1.2048
2.18568	1.4500	1.4240	2.3680	1.7480	1.2120
2.25695	1.4075	1.4020	2.3330	1.8050	1.2253
2.32822	1.3650	1.3770	2.3000	1.8620	1.2344
2.37574	1.3410	1.3560	2.2780	1.9000	1.2411
2.42325	1.3200	1.3330	2.2556	1.9380	1.2488
2.47074	1.3000	1.3060	2.2310	1.9760	1.2585
2.51828	1.2825	1.2730	2.2050	2.0140	1.2700
2.54204	1.2750	1.2550	2.1900	2.0330	1.2760
2.56580	1.2655	1.2320	2.1750	2.0520	1.2825
2.61331	1.2500	1.1800	2.1430	2.0900	1.2965
2.65132	1.2400	1.1310	2.1160	2.1204	1.3085

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 360.0 °K

$\mathfrak{M}_1$ = 0.021 sec/kg

dT1 sq.ft. $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.71053	1.4650	1.6050	2.5600	1.5120	1.1670
1.74142	1.4400	1.5880	2.5380	1.5393	1.1750
1.80556	1.4050	1.5490	2.4990	1.5960	1.18[illegible]
1.85308	1.3820	1.5160	2.4700	1.6380	1.1998
1.90059	1.3620	1.4850	2.4430	1.6800	1.2094
1.94811	1.3480	1.4600	2.4170	1.7220	1.2185
2.01938	1.3315	1.4280	2.3820	1.7850	1.2309
2.09065	1.3110	1.3980	2.3500	1.8480	1.2417
2.13817	1.2950	1.3800	2.3300	1.8900	1.2486
2.28071	1.2430	1.3260	2.2630	2.0160	1.2718
2.35198	1.2180	1.2950	2.2290	2.0790	1.2833
2.39950	1.2030	1.2740	2.2085	2.1210	1.2908
2.47077	1.1815	1.2350	2.1775	2.1840	1.3020
2.51828	1.1665	1.2030	2.1540	2.2260	1.3110
2.56580	1.1500	1.1650	2.1280	2.2680	1.3219
2.61331	1.1320	1.1230	2.1000	2.3100	1.3335

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 360.0 °K

$\mathfrak{M}_1$ = 0.023 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.94811	1.1500	1.4250	2.3600	1.8860	1.2690
2.04314	1.1330	1.3800	2.3130	1.9780	1.2849
2.09065	1.1250	1.3590	2.2910	2.0240	1.2921
2.16192	1.1110	1.3280	2.2620	2.0930	1.3021
2.23319	1.0980	1.2960	2.2330	2.1620	1.3106
2.28071	1.0900	1.2740	2.2120	2.2080	1.3179
2.32822	1.0800	1.2500	2.1900	2.2540	1.3265
2.37574	1.0680	1.2250	2.1660	2.3000	1.3362
2.42325	1.0550	1.1940	2.1410	2.3460	1.3469
2.47077	1.0410	1.1580	2.1160	2.3920	1.3582
2.53254	1.0200	1.1060	2.0820	2.4518	1.3741

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 360.0 °K

L. P. Surge Line

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.66302	1.5100	1.6200	2.6000	1.4700	1.1540
1.71053	1.4100	1.5750	2.5430	1.5390	1.1760
1.75805	1.3200	1.5400	2.4970	1.6090	1.1980
1.80556	1.2500	1.5180	2.4570	1.6790	1.2180
1.85308	1.2050	1.4860	2.4210	1.7490	1.2370
1.90059	1.1740	1.4550	2.3900	1.8190	1.2540
1.99562	1.1250	1.3970	2.3300	1.9460	1.2830
2.09065	1.0870	1.3480	2.2800	2.0580	1.3050
2.18568	1.0560	1.3050	2.2330	2.1640	1.3220
2.28071	1.0300	1.2540	2.1880	2.2660	1.3400
2.35198	1.0140	1.2110	2.1540	2.3410	1.3550
2.42325	0.9970	1.1610	2.1180	2.4160	1.3700
2.49928	0.9780	1.1000	2.0780	2.4930	1.3880

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 389.7 °K

Fan choke region

dT1 sq.ft $\sqrt{°R}/s$	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.760430	2.2250	1.2250	2.3750	1.1100	1.1260
1.901830	2.0600	1.2000	2.3050	1.2000	1.1450
2.139382	1.8000	1.1380	2.1820	1.3500	1.1800
2.305527	1.6350	1.0850	2.0910	1.4250	1.2070
2.376934	1.5900	1.0500	2.0500	1.4700	1.2210
2.425010	1.5600	1.0200	2.0200	1.5100	1.2320
2.470965	1.5450	0.9750	1.9920	1.5500	1.2440
2.519041	1.5300	0.9220	1.9620	1.590[illegible]	1.2570
2.566410	1.5250	0.8550	1.9300	1.6200	1.2720
2.637110	1.5200	0.7250	1.8750	1.6650	1.2960

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 389.7 °K

$\eta 1 = 0.017$ sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.563571	2.1280	1.2690	2.4110	1.1900	1.1220
1.830423	1.9730	1.2520	2.3330	1.3090	1.1390
1.973237	1.8380	1.2300	2.2620	1.4110	1.1560
2.139382	1.6870	1.1900	2.1770	1.5300	1.1800
2.305527	1.5410	1.1280	2.0920	1.6490	1.2070
2.376934	1.4890	1.0800	2.0550	1.7000	1.2210
2.448341	1.4450	1.0320	2.0130	1.7510	1.2360
2.543079	1.4020	0.9390	1.9490	1.8190	1.2610
2.614486	1.3810	0.8540	1.8980	1.8700	1.2840

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 389.7 °K

$\eta 1$ = 0.019 sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.615500	1.08700	1.3700	2.4200	1.2920	1.1140
1.783054	1.7500	1.3100	2.3200	1.4250	1.1430
1.901830	1.6700	1.2600	2.2550	1.5200	1.1640
2.020606	1.5900	1.2100	2.1920	1.6150	1.1850
2.139382	1.5150	1.1600	2.1350	1.7100	1.2060
2.258158	1.4400	1.1100	2.0800	1.8050	1.2260
2.376934	1.3800	1.0500	2.0250	1.9000	1.2460
2.448341	1.3450	1.0100	1.9900	1.9570	1.2570
2.543079	1.3100	0.9320	1.9320	2.0330	1.2760
2.637110	1.2900	0.8250	1.8750	2.1090	1.3020

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 389.7 °K

$\mathfrak{M}1$ =0.021 sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.569540	1.5700	1.3900	2.3850	1.3860	1.1360
1.663571	1.5050	1.3350	2.3200	1.4700	1.1590
1.783054	1.4450	1.2700	2.2500	1.5750	1.1860
1.901830	1.4000	1.2050	2.1850	1.6800	1.2080
2.020606	1.3650	1.1450	2.1250	1.7850	1.2280
2.139382	1.3350	1.0870	2.0700	1.8900	1.2470
2.258158	1.2950	1.0300	2.0200	1.9950	1.2640
2.376934	1.2500	0.9650	1.9650	2.1000	1.2820
2.495710	1.2100	0.8850	1.9050	2.2050	1.3060
2.543079	1.1900	0.8500	1.8800	2.2470	1.3160

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 389.7 °K

$\mathfrak{M}1 = 0.025$ sec/kg

dT1 sq.ft $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.973237	1.2000	1.1350	2.0950	1.9090	1.2660
2.139382	1.1400	1.0430	2.0200	2.0700	1.3000
2.258158	1.1150	0.9700	1.9650	2.1850	1.3200
2.376934	1.0850	0.8850	1.9050	2.3000	1.3400
2.425010	1.07200	0.8500	1.8800	2.3460	1.3470

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 420 °K

$\eta 1 = 0.017$ sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.615503	2.2800	1.3500	2.3130	1.1560	1.0700
1.663018	2.2220	1.3020	2.2750	1.1900	1.0840
1.758047	2.1060	1.2160	2.1980	1.2580	1.1100
1.829320	2.0200	1.1600	2.1440	1.3090	1.1270
1.900592	1.9360	1.1100	2.0950	1.3600	1.1420
1.971864	1.8550	1.0670	2.0480	1.4110	1.1560
1.995621	1.8300	1.0575	2.0350	1.4280	1.1600
2.090651	1.7250	1.0370	2.0090	1.4960	1.1720
2.138166	1.6800	1.0225	1.9630	1.5300	1.1770
2.185681	1.6400	1.0000	1.9390	1.5640	1.1840
2.268832	1.5800	0.9550	1.8950	1.6235	1.1990

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 420 °K

η_1 = 0.019 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.508595	2.0400	1.3500	2.3150	1.2065	1.0820
1.591746	1.9500	1.2870	2.2530	1.2750	1.1000
1.710533	1.8330	1.2050	2.1680	1.3680	1.1255
1.781805	1.7670	1.1600	2.1200	1.4250	1.1400
1.853077	1.7060	1.1150	2.0740	1.4820	1.1547
1.948107	1.6360	1.0650	2.0160	1.5580	1.1730
2.043136	1.5730	1.0210	1.9640	1.6340	1.1900
2.138166	1.5200	0.9750	1.9190	1.7100	1.2050
2.202311	1.4900	0.9400	1.8880	1.7615	1.2130

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 420.0 °K

$\mathfrak{M}_1$ = 0.021 sec/kg

dT1 sq. ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.420692	1.7800	1.3500	2.2980	1.2558	1.0950
1.472960	1.7190	1.3100	2.2570	1.3020	1.1080
1.544231	1.6410	1.2600	2.2040	1.3650	1.1250
1.615503	1.5740	1.2115	2.1540	1.4280	1.1425
1.686775	1.5170	1.1670	2.1050	1.4910	1.1600
1.734290	1.4860	1.1365	2.0730	1.5330	1.1710
1.853077	1.4390	1.0650	2.0010	1.6380	1.1975
1.948107	1.4040	1.0080	1.9500	1.7220	1.2160
2.019379	1.3800	0.9680	1.9140	1.7850	1.2285
2.097778	1.3600	0.9240	1.8750	1.8543	1.2400

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 420.0 °K

L. P. SURGE LINE

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.401687	1.7550	1.3500	2.3100	1.2750	1.0915
1.472960	1.6250	1.2980	2.2350	1.3500	1.1192
1.544231	1.5100	1.2410	2.1670	1.4250	1.1461
1.615503	1.4100	1.1900	2.1050	1.5050	1.1720
1.663018	1.3500	1.1520	2.0680	1.5600	1.1890
1.734290	1.3080	1.0925	2.0170	1.6450	1.2120
1.781805	1.2830	1.0530	1.9860	1.7050	1.2250
1.876835	1.2340	0.9910	1.9290	1.8200	1.2460
1.955234	1.1950	0.9490	1.8850	1.9100	1.2615

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 450.0 °K

$\mathfrak{M}_1$ = 0.015 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
2.092720	1.9150	0.7800	1.7870	1.3200	1.1750
2.138675	1.8650	0.7600	1.7600	1.3500	1.1830
2.184630	1.8100	0.7350	1.7320	1.3800	1.1900
2.234120	1.7650	0.7050	1.7120	1.4100	1.1980
2.280075	1.7200	0.6800	1.6800	1.4400	1.2060
2.329565	1.6800	0.6440	1.6540	1.4700	1.2140
2.375520	1.6450	0.6120	1.6300	1.5000	1.2235
2.421475	1.6100	0.5700	1.6040	1.5300	1.2330
2.470965	1.5800	0.5250	1.5820	1.5600	1.2435
2.519041	1.5500	0.4650	1.5600	1.5900	1.2550

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 450.0 °K

$\mathfrak{M}_1$ = 0.017 sec/kg

dT1 sq.ft. $\sqrt{°R}$/S	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.378650	2.3050	1.2900	2.2400	0.9860	1.0440
1.544795	2.2500	1.1850	2.1450	1.1050	1.0680
1.661450	2.1900	1.1080	2.0700	1.1900	1.0875
1.781640	2.1000	1.0250	1.9900	1.2750	1.1110
1.898295	1.9700	0.9400	1.9050	1.3600	1.1360
1.993740	1.8630	0.8850	1.8420	1.4280	1.1550
2.089185	1.7750	0.8370	1.7950	1.4960	1.1680
2.184630	1.6950	0.7900	1.7450	1.5640	1.1825
2.280075	1.6470	0.7300	1.6920	1.6320	1.1980
2.375520	1.5550	0.6500	1.6400	1.7000	1.2160
2.423250	1.5250	0.6000	1.6170	1.7340	1.2260
2.467430	1.5000	0.5400	1.5930	1.7650	1.2370

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 450.0 °K

$\mathfrak{M}_1$ = 0.019 sec/kg

dT_1 sq.ft. $\sqrt{°R}/s$	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.211091	2.1900	1.3570	2.3200	0.9690	1.0260
1.306536	2.1400	1.2970	2.2520	1.0450	1.0440
1.424605	2.0700	1.2200	2.1650	1.1400	1.0680
1.544795	1.9900	1.1420	2.0820	1.2350	1.0910
1.661450	1.9000	1.0570	2.0000	1.3300	1.1150
1.760430	1.8200	0.9900	1.9360	1.4050	1.1350
1.802850	1.7820	0.9520	1.9150	1.4440	1.1450
1.898295	1.7120	0.8950	1.8500	1.5200	1.1630
1.993740	1.6550	0.8400	1.7920	1.5950	1.1800
2.089185	1.6050	0.7820	1.7470	1.6700	1.1955
2.184630	1.5500	0.7250	1.6990	1.7470	1.2050
2.280075	1.4980	0.6680	1.6520	1.8240	1.2260
2.394740	1.4300	0.6000	1.5970	1.9200	1.2490

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 450.0 °K

η_1 = 0.021 sec/kg

dT1 sq.ft. $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.140391	[illegible]	1.3800	2.3380	1.0080	1.0220
1.306536	1.9000	1.2550	2.1900	1.1550	1.0660
1.424605	1.7700	1.1800	2.0930	[illegible]	1.0970
1.544795	1.6400	1.0800	2.0050	1.3650	1.1260
1.661450	1.5450	0.9920	1.9200	1.4710	1.1540
1.760430	1.5100	0.9260	1.8620	1.5550	1.1750
1.802850	1.5020	0.8900	1.8350	1.5960	1.1850
1.852340	1.4930	0.8570	1.8050	1.6380	1.1950
1.898295	1.4800	0.8250	1.7800	1.6600	1.2050
1.993740	1.4450	0.7620	1.7290	1.7650	1.2225
2.089185	1.4120	0.7000	1.6810	1.8500	1.2390
2.184630	1.3800	0.6450	1.6360	1.9320	1.2535
2.315425	1.3370	0.5750	1.5830	2.0450	1.2690

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 450.0 °K

$\mathfrak{M}_1 = 0.023$ sec/kg

dT1 sq.ft. $\sqrt{°R}/s$	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.068984	1.9350	1.4050	2.3570	1.0350	1.0195
1.187760	1.7450	1.3000	2.2350	1.1500	1.0570
1.306536	1.5800	1.2080	2.1200	1.2650	1.0950
1.424605	1.4500	1.1160	2.0200	1.3800	1.1310
1.544795	1.3800	1.0300	1.9400	1.4950	1.1600

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 450.0 °K

$\mathfrak{M}_1$ = 0.025 sec/kg

dT1 sq.ft. $\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
0.997577	1.7800	1.4050	2.3680	1.0510	1.0240
1.092315	1.5800	1.3250	2.2530	1.1500	1.0570
1.177862	1.4080	1.2550	2.1550	1.2400	1.0890

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 450.0 °K

L. P. Surge Line

dT1 sq.ft. $\sqrt{°R}/s$	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
0.950208	1.3500	1.3400	2.2750	1.1360	1.0590
1.068984	1.3900	1.3000	2.2150	1.1900	1.0730
1.187760	1.4050	1.2500	2.1500	1.2450	1.0910
1.306536	1.4100	1.1900	2.0800	1.3150	1.1120
1.424605	1.4000	1.1150	2.0100	1.3860	1.1350
1.544795	1.3800	1.0300	1.9380	1.4820	1.1600
1.661450	1.3500	0.9340	1.8650	1.5830	1.1893
1.760430	1.3180	0.8810	1.8090	1.6650	1.2107
1.852340	1.2740	0.8060	1.7500	1.7550	1.2358
1.947785	1.2400	0.7280	1.6890	1.8450	1.2619
1.993740	1.2240	0.6940	1.6630	1.8900	1.2723
2.043230	1.2150	0.6590	1.6410	1.9350	1.2806
2.089185	1.2180	0.6270	1.6210	1.9800	1.2873
2.138160	1.2280	0.5950	1.6020	2.0250	1.2928
2.184630	1.2450	0.5600	1.5840	2.0800	1.2980

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 550.0°K

$\mathcal{M}_1$ = 0.017 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.33041	2.6700	1.1000	1.8550	0.9520	1.0230
1.42544	2.5900	1.0000	1.7800	1.0200	1.0410
1.52047	2.5050	0.9000	1.7070	1.0890	1.0590
1.59174	2.4350	0.8300	1.6550	1.1390	1.0720
1.66302	2.3600	0.7650	1.6050	1.1900	1.0860
1.73429	2.2800	0.7000	1.5550	1.2400	1.1000
1.80556	2.2000	0.6400	1.5050	1.2910	1.1140
1.87683	2.1180	0.5850	1.4520	1.3420	1.1280
1.94810	2.0300	0.5350	1.4000	1.3930	1.1420

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 550.0 °K

$\mathfrak{M}1 = 0.019$ sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.21162	2.5600	1.1050	1.9000	0.9690	1.0170
1.30665	2.4500	1.0070	1.8050	1.0460	1.0390
1.37793	2.3600	0.9400	1.7480	1.1010	1.0540
1.47296	2.2400	0.8550	1.6710	1.1790	1.0740
1.56799	2.1250	0.7700	1.5980	1.2530	1.0940
1.66302	2.0300	0.6900	1.5280	1.3300	1.1130
1.75804	1.9400	0.6170	1.4630	1.4060	1.1320
1.85307	1.8600	0.5550	1.4050	1.4810	1.1500
1.92435	1.8000	0.5150	1.3700	1.5390	1.1630

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 550.0 °K

$\mathfrak{M}_1$ = 0.021 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.14035	2.5500	1.1250	1.9050	1.0080	1.0180
1.21162	2.3200	1.0300	1.8200	1.0710	1.0390
1.23538	2.2550	1.0050	1.7950	1.0920	1.0460
1.28290	2.1500	0.9540	1.7500	1.1330	1.0600
1.33041	2.0600	0.9040	1.7070	1.1780	1.0720
1.37793	1.9850	0.8550	1.6650	1.2180	1.0830
1.42544	1.9200	0.8100	1.6260	1.2600	1.0940
1.47296	1.8650	0.7700	1.5900	1.3010	1.1050
1.52047	1.8200	0.7280	1.5500	1.3430	1.1160
1.59174	1.7550	0.6700	1.4950	1.4080	1.1310
1.68677	1.6850	0.6000	1.4350	1.4910	1.1510
1.78180	1.6230	0.5420	1.3900	1.5750	1.1690
1.90059	1.5600	0.4850	1.3400	1.6800	1.1910

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 550.0 °K

$\mathfrak{M}_1$ = 0.023 sec/kg

dT1 sq.ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
1.02157	2.8000	1.2100	2.0100	0.9890	1.0070
1.06908	2.5000	1.1400	1.9370	1.0340	1.0210
1.11660	2.2200	1.0700	1.8680	1.0810	1.0370
1.14035	2.1000	1.0400	1.8350	1.1030	1.0445
1.16411	2.0050	1.0100	1.8050	1.1280	1.0520
1.18787	1.9300	0.9800	1.7750	1.1500	1.0595
1.21162	1.8600	0.9550	1.7480	1.1720	1.0670
1.23538	1.8000	0.9280	1.7220	1.1970	1.0740
1.25914	1.7600	0.9000	1.6970	1.2190	1.0810
1.28290	1.7200	0.8760	1.6750	1.2410	1.0880
1.33041	1.6600	0.8280	1.6320	1.2890	1.1020
1.40168	1.5800	0.7600	1.5720	1.3580	1.1215
1.47296	1.5200	0.6950	1.5150	1.4270	1.1400
1.53948	1.4700	0.6400	1.4650	1.4900	1.1570

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 550.0 °K

$\mathfrak{M}_1 = 0.025$ sec/kg

dT1 sq. ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
0.95029	2.6000	1.1950	2.0100	1.0000	1.0110
0.99781	2.3000	1.1240	1.9300	1.0500	1.0260
1.04532	2.0300	1.0600	1.8580	1.1000	1.0410
1.09284	1.8030	1.0030	1.7950	1.1500	1.0560
1.11660	1.7100	0.9750	1.7650	1.1750	1.0640
1.14035	1.6400	0.9450	1.7400	1.2000	1.0710
1.17361	1.5600	0.9050	1.7050	1.2320	1.0810

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 550.0 °K

$\mathfrak{M}_1 = 0.027$ sec/kg

dT1 sq. ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
0.90278	2.4000	1.1650	2.0000	1.0260	1.0190
0.95029	2.0400	1.0950	1.9100	1.0800	1.0345
0.99781	1.7500	1.0300	1.8300	1.1330	1.0500
1.03107	1.5900	0.9900	1.7800	1.1700	1.0610

S N E C M A

TF 106 - TURBOFAN ENGINE

Maximum Rated Turbine Inlet Temperature

Engine inlet temperature : 550.0 °K

L. P. Surge Line

dT1 sq. ft.$\sqrt{°R}$/s	β	P'7/P1	T'7/T1	PF2/P1	TF2/T1
0.95029	1.5990	1.0310	1.8155	1.1520	1.0539
0.99781	1.5920	1.0070	1.7966	1.1630	1.0575
1.04532	1.5850	0.9825	1.7750	1.1770	1.0[illegible]
1.11660	1.5720	0.9416	1.7380	1.2060	1.0[illegible]
1.18787	1.5570	0.8975	1.6975	1.2420	1.0834
1.25914	1.5390	0.8500	1.6545	1.2850	1.0965
1.33041	1.5200	0.8000	1.6080	1.3330	1.1110
1.42544	1.4950	0.7290	1.5445	1.4070	1.1315
1.56799	1.4610	0.6190	1.4415	1.5180	1.1643

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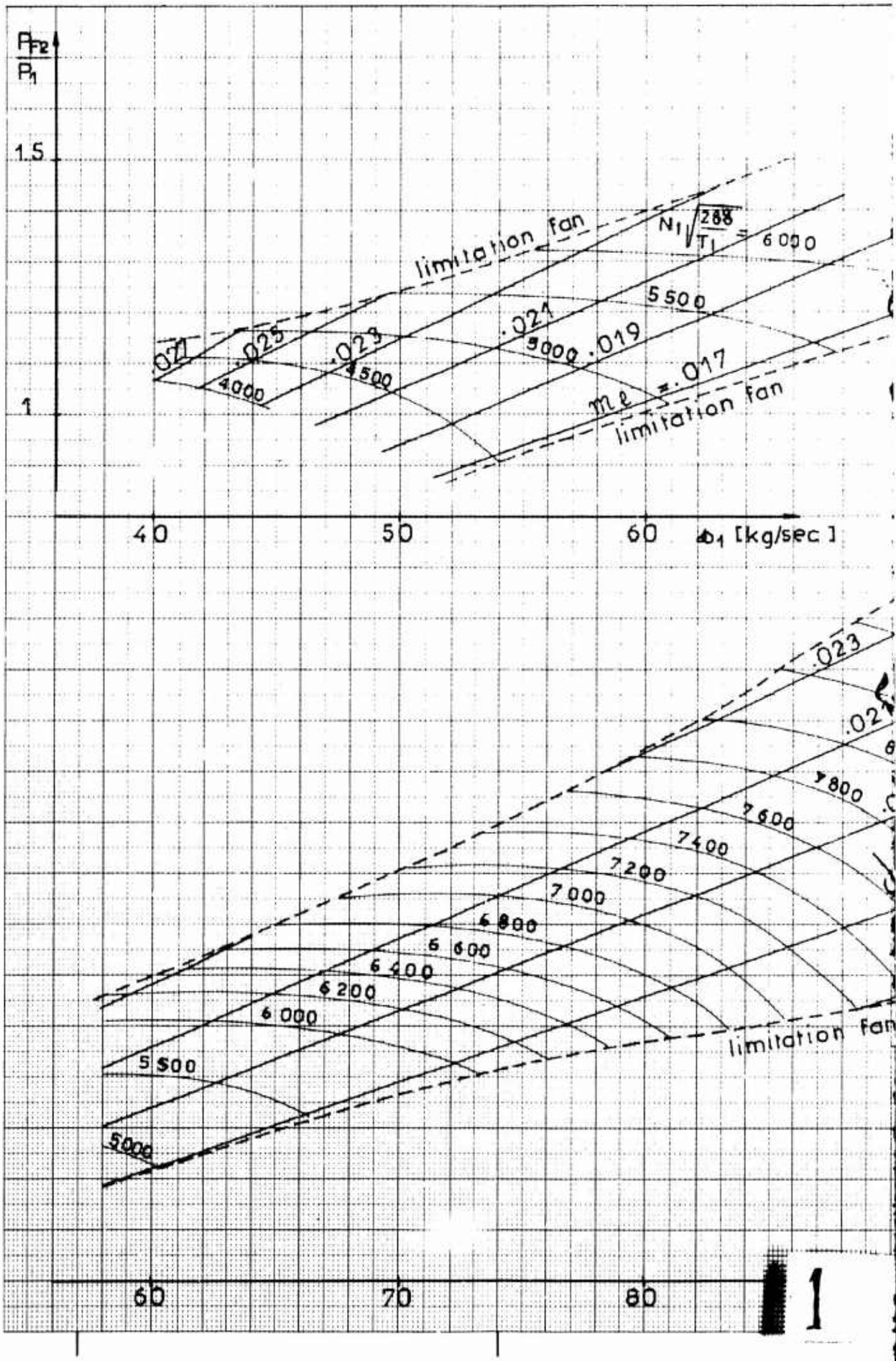

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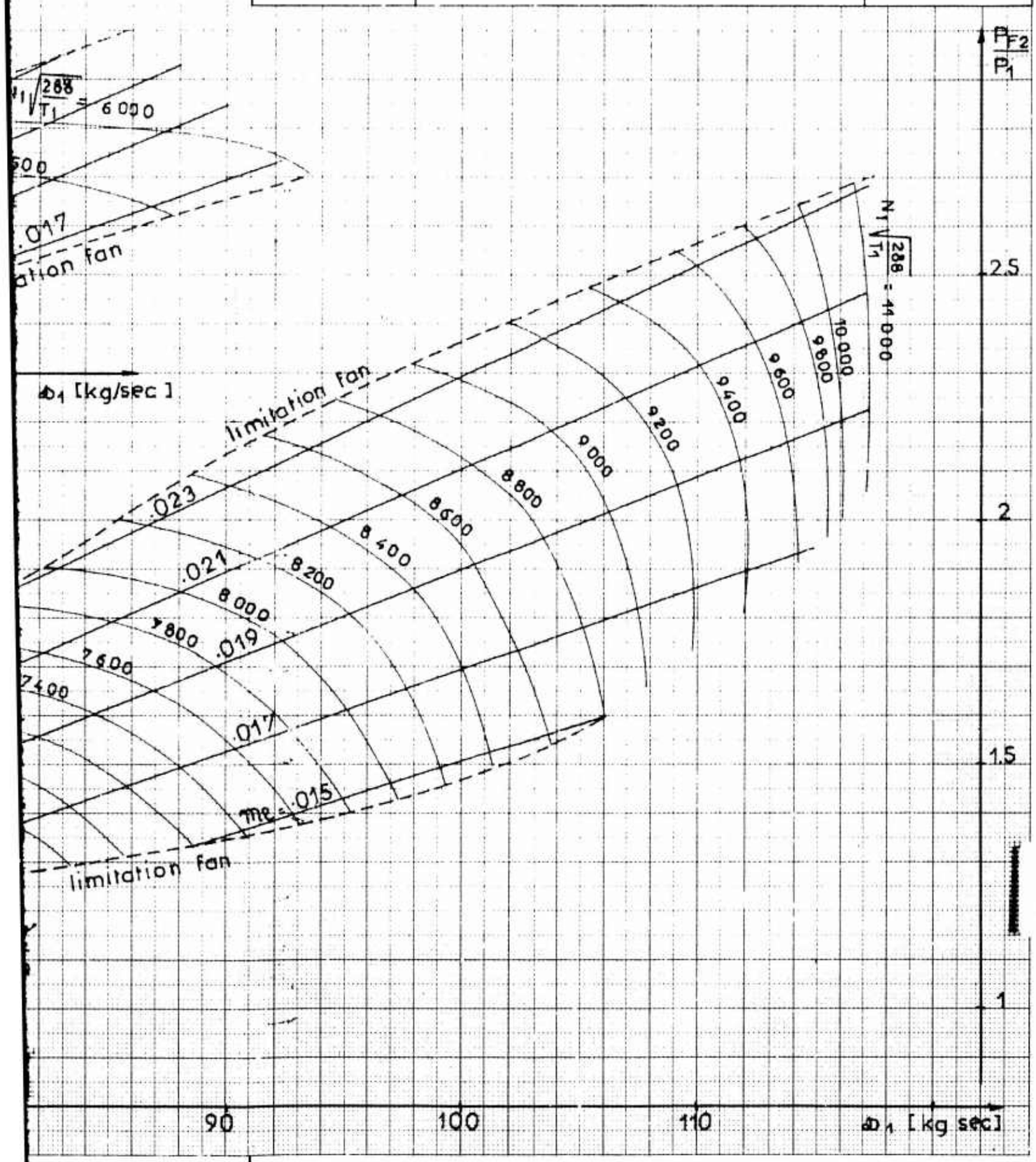

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October 1965

FINAL REPORT

EXPERIMENTAL AND DESIGN STUDIES FOR TURBO-RAMJET COMBINATION ENGINE

Volume 3.2 - GENERAL DATA

NORD-AVIATION

DEPARTEMENT "PROPULSEURS"

PARIS (CHATILLON), FRANCE

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SUMMARY

In this note, we state the numerical values of the various coefficients and functions which establish the efficiency of the various sections of the turbofan-ramjet combination engine built around the SNECMA TF 106 turbofan. In particular we state :

- the air inlet pressure recovery
- the head losses in the ramjet duct opening into the flow mixer
- the head losses in the mixer-diffuser assembly
- the ratio of air bleed for ancillaries
- the kerosene heating value
- the geometrical coefficients and flow coefficients of the pilot burner
- the flame holders drag coefficients of the primary and annular combustion systems
- the combustion efficiencies
- the exit nozzle coefficients for each nozzle configuration

We specify, when necessary, the limits adopted for the various parameters.

Finally, we give the numerical values of the various basic cross-sectional areas of the combination engine.

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Fig. 5 Annular combustion system - combustion efficiency in terms of equivalence ratio.

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SYMBOLS

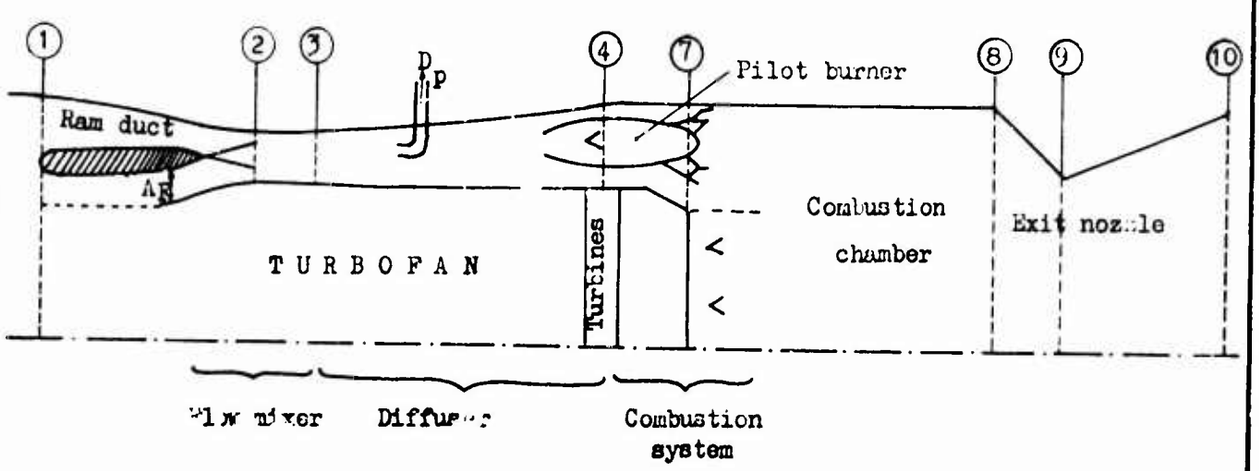
Superscripts

'	indicates turbofan primary flow parameters
"	indicates annular flow parameters

Subscripts

R	ramjet flow
T	turbofan total flow, or turbofan regarded as a whole
F	turbofan secondary flow
H	annular flow passing through the pilot burner of the annular combustion system
c	annular flow passing round the pilot burner
B	combination engine combustion chamber
o	is characteristic of the upstream infinite

Numerical subscripts refer to various stations as shown in the diagram below :



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General symbols

A	Area of a cross-section
A_F	Turbofan secondary exit cross-sectional area
P	Total pressure
p	Static pressure
T	Total temperature
M	Mach number
γ	Isentropic coefficient
D	Air flow
D_p	Bleed air flow
μ	Air bleed coefficient $= D_p / D''$
λ	Pilot burner f[illegible] coefficient $= D''_H / D''$
K	Pilot burner geometrical coefficient $= A''$ [illegible] $/ A''_4$
τ	Flame holders drag coefficient
η'_B	Combustion efficiency of the primary afterburner
η''_B	Combustion efficiency of the annular combustion system
r''_{Bb}	Burned equivalence ratio in the annular combustion system
$r_{b\ opt}$	Burned equivalence ratio corresponding to maximum efficiency of the annular combustion system
$r'_{b\ opt}$	Burned equivalence ratio corresponding to maximum efficiency of the pilot burner
φ	Exit nozzle coefficient
η_d	Diffuser isentropic efficiency

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1 - INTRODUCTION

In this note, we bring together the numerical values of the various coefficients and functions which establish the efficiencies of the various parts of the turbofan-ramjet engine built around the SNECMA TF 106 turbofan. We also give the numerical values of the combination engine basic cross section areas.

2 - AIR INLET TOTAL PRESSURE RECOVERY

The engine performance characteristics are calculated with total pressure recovery law $P_1 / P_o \ (M_o)$:

- in subsonic flight $P_1 / P_o = 1$
- in supersonic flight, we have adopted the figures of the US SPECIFICATION MIL-E-5008 B

$$P_1 / P_o = 1 - 0.075 \ (M_o - 1)^{1.35}$$

The engine regulation is designed so that the air inlet operates at its maximum pressure recovery ratio for all normal utilization ratings of the powerplant.

Fig. 1 illustrates the law adopted for supersonic flight.

The influence of this ratio P_1 / P_o on the performance characteristics is explained in Vol. 1 - SPECIFICATIONS AND PERFORMANCE.

3 - HEAD LOSSES IN THE RAM DUCT

The calculation program makes provisions for the introduction of head losses in the ram duct opening out into the mixer.

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The tests carried out under cover of the previous contract AF 61 (052)-670 concerning the interaction of the ramjet and turbofan flows at the engine inlet, have enabled us to define an inlet contour for the turbofan which gives entire satisfaction at all operating modes, in particular for the pure turbofan operating mode (the ram duct being shut off) and for the pure ramjet operation (the turbofan being stopped). See Vol. 4 of contract AF 61 (052)-670 : INLET FLOW STUDIES.

Considering these test results, we have chosen a pressure ratio P_{R2} / P_1 equal to 1 for all the calculations.

4 - HEAD LOSSES IN THE FLOW MIXER-DIFFUSER ASSEMBLY

The mixture characteristics of the secondary and ramjet flows are calculated in the program with the assumption that the mixing takes place inside a constant-cross-section chamber ; a diffuser follows in which the flow velocity slows down to a value acceptable for the annular combustion system. The head losses in the diffuser can theoretically be characterized by a diffuser efficiency, η_d , such that :

$$\frac{P''_4}{P''_3} = \left[\frac{1 + \eta_d \frac{\gamma_3 - 1}{\gamma_3} M''^2_3}{1 + \frac{\gamma_3 - 1}{\gamma_3} M''^2_3} \right]^{\frac{\gamma_3}{\gamma_3 - 1}}$$

The tests on the mixer-diffuser assembly, carried out under cover of the previous contract AF 61 (052)-670, were

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analyzed with adopting the calculation diagram of the calculation program ; from these tests, we have deduced total pressure losses in the diffuser, P''_4 / P''_3 which include not only the losses due to the diffuser alone but also those due to the [illegible].

Such a presentation permits easy access of the losses attributable to the mixer-diffuser assembly into the calculation program. See Vol. 5 of Contract AF 61 (052)-670 : FLOW MIXER STUDIES.

These tests also covered the pure ramjet and pure turbofan operating modes.

The laws of head losses P''_4 / P''_3 in the diffuser were then determined with regard to these test results.

4.1 - Pure turbofan operating mode

We have adopted the test results. The diffuser head losses, P''_4 / P''_3 , are given in terms of the Mach number, M_F , of the secondary flow in the secondary exit cross-section of the turbofan, A_F (see Fig. 53 of Vol. 5 of the previous contract).

M_F	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$\frac{P''_4}{P''_3}$	1	0.997	0.993	0.988	0.982	0.975	0.966	0.956	0.943	0.926	0.904

This law corresponds to a diffuser isentropic efficiency close to 0.89.

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4.2 - Pure ramjet operating mode

We have adopted the test results. The law of head losses corresponds to a diffuser isentropic efficiency equal to 0.91, the Mach number at the mixer throat M''_3 being taken as parameter (see para. 6.2.3 of Vol. 5 of the previous contract).

M''_3	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$\frac{P''_4}{P''_3}$	1	0.9995	0.9975	0.9945	0.9905	0.9855	0.979	0.973	0.965	0.957	0.948

It should be noticed that the duct, in the pure turbofan configuration, is more distorted, in the vicinity of the turbofan secondary exit, than that of the pure ramjet configuration ; this can justify why the isentropic efficiency of the diffuser is better in the pure ramjet configuration than in the pure turbofan configuration.

4.3 - Mixed flows operating mode

The research works performed by Nord-Aviation about the flow mixer system have shown the possibility of mixing, over a short distance, two annular and concentric flows. But the results obtained at the completion of this study have shown that the mixture obtained is too energetic (see para. 6.5.3 of Vol. 5 of the previous contract). This system remains to be optimized by a convenient choice of the shape, orientation, length, and number of the flaps in the staggered flap type flow mixer.

We have adopted the following law, with Mach number M''_3 at the mixer throat being a parameter :

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M''_3	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$\frac{P''_4}{P''_3}$	1	0.997	0.992	0.986	0.980	0.970	0.958	0.944	0.925	0.902	0.872

On Fig. 2 we show the three laws P''_4/P''_3 adopted for the calculations of the combination engine cycle and performance characteristics.

5 - AIR BLEED FOR THE ANCILLARIES

The calculation program makes provisions for air bleed in the diffuser following the mixer, for powering the ancillaries. The bleed air flow D_p is defined by coefficient $\mu = D_p/D''$

All the calculations were carried out with $\mu = 0$

6 - COMBUSTION CHAMBER

The combus[illegible]em makes it possible to inject fuel into the annular flow, and [illegible] primary flow delivered by the turbofan. The annular combus[illegible] was designed so as to permit flights with very lean equivalence ratios, the primary system being used for acceleration flights.

6.1 - Kerosene lower heating value

The lower heating value of kerosene is set equal to 18,630 BTU/lb.

6.2 - Annular combustion system

Part of the annular air flow is tapped by the pilot burner, so as to permit combustions at very lean, overall equivalence ratios; external fuel injectors make it possible to enrich the air surrounding the pilot burner.

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6.2.1 - Flow coefficient, λ

The flow coefficient λ determines the proportion of annular air flow tapped by the pilot burner :

$$\lambda = D''_H / D''$$

Measurements made on the combustion system test model at Les Gâtines have enabled us to calculate this coefficient. Its obtained average value has been adopted for all the calculations of performance characteristics :

$$\lambda = 0.12$$

6.2.2 - Geometrical coefficient, K

The geometrical coefficient makes it possible to define the passage cross section area of the annular flow passing round the pilot burner, in section 7. The adopted value corresponds to the definition of the annular combustion system test model :

$$K = 0.58$$

6.3 - Flame holders drag coefficients

The combustion systems cause a drag which results in a head loss and is equal to :

$$\frac{1}{2} \gamma p A M^2 \tau$$

in which

- τ is a drag coefficient, function of Mach number M.
- p and M are the static pressure and the Mach number which would exist ahead of the combustion systems if the latter were placed in section A.

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- A is the cylindrical cross section area of the flows :

For the primary flow $A = A'_7$

For the annular flow $A = A''_7 = A''_{7H} + A''_{7c}$

Since the flame holders in the primary flow are more pervious than those in the annular flow, we have adopted two different laws, $\tau'(M'_7)$ and $\tau''(M''_7)$, for each of these two flows.

The laws adopted for the performance characteristics calculations are those adopted in the previous contract AF 61 (052)-670 : TURBOFAN RAMJET ENGINE STUDIES, since the analyses of the combustion tests have not progressed sufficiently for adopting the values obtained on the models.

On Fig. 3 we give the law $\tau'(M'_7)$

For coefficient τ'' we have adopted the constant value $\tau'' = 2$, since M''_7 is always low.

Those values were derived from data issuing from flight tests on the GRIFFON and bench tests on ramjet-powered missile of Nord-Aviation.

6.4 - Combustion efficiency

6.4.1 - Primary combustion system

We have adopted for the primary flow reheating system a constant combustion efficiency :

$$\eta'_B = 0.90$$

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6.4.2 - Annular combustion system

We have adopted a very flexible, general law in which the combustion efficiency is a function of the total temperature T''_3 at the combustion chamber inlet, of the total pressure P''_4 and of the burned equivalence ratio r''_{Bb}. The coefficients of these equations were determined partly in function of the results of combustion tests on the annular system, obtained at the time when the performance characteristics calculations were undertaken, and partly in function of the experience gained by Nord-Aviation on combustion efficiencies inside the combustion chambers of ramjets and of the GRIFFON aircraft powered by a turbo-ramjet combination engine.

The combustion system can operate on two ratings :

- for low equivalence ratios, the fuel is injected by he grid of the pilot burner ;
- for high equivalence ratios, the fuel is injected by the assembly of inner and outer grids of the pilot burner.

We have assumed that

- both ratings lead to the same maximum efficiency η_{max} under the same temperature and pressure conditions at the chamber inlet ;
- the maximum combustion efficiency of the pilot burner is attained when the burned equivalence ratio is $r'_{b\ opt} = 0.25$;
- the maximum combustion efficiency of the complete system is attained when the burned equivalence

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ratio is $r_{b\ opt} = 0.70$

It should be noticed that the positions of these maximums are a matter of adaptation of the combustion system assembly.

6.4.2.1 - Maximum efficiency (Fig. 4)

The maximum efficiency is given by the following equation :

$$\eta_{max} = 0.95 - e^{-8.1 \times 10^{-4} \times P''_4} \left[0.2 + e^{-0.0049(T''_3 - 414)} \right]$$

in which the pressure is expressed in lb/sq.ft and the temperature in °R.

6.4.2.2 - Variation with equivalence ratio (Fig. 5)

- Operation on the pilot burner alone :

$$\eta''_B = \eta_{max} - 5\,u'^2 \qquad \text{with } u' = r''_{Bb} - r'_{b\ opt} > 0$$

$$\eta''_B = \eta_{max} - (1.67\,u'^2 - 33.3\,u'^3)$$

$$\text{with } u' = r''_{Bb} - r'_{b\ opt} < 0$$

- Operation on the complete system :

$$\eta''_B = \eta_{max} - (1.67\,u^2 + 33.33\,u^3)$$

$$\text{with } u = r''_{Bb} - r_{b\ opt} > 0$$

$$\eta''_B = \eta_{max} - (0.39\,u^2 - 0.55\,u^3)$$

$$\text{with } u = r''_{Bb} - r_{b\ opt} < 0$$

6.4.2.3 - Maximum burned equivalence ratio

We define a maximum burned equivalence ratio, $r_{b\ max}$, which corresponds to a calculation limit, with

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the purpose of retaining acceptable combustion efficiencies. This maximum equivalence ratio is given by a law that is a function of the total temperature, T''_3 and of the total pressure P''_4 at the inlet of the combustion chamber (see Vol. 2.1, CYCLE ANALYSIS). For the calculations of performance characteristics, we have adopted a constant value equal to 0.8 ; the coefficients defining this maximum efficiency have the following values :

$$\alpha_c = 0.8 \quad \alpha'_c = 1 \quad \beta_c = 0 \quad \beta'_c = 0$$

7 - EXIT NOZZLE

The exit nozzle is common to both annular and primary flows.

7.1 - Maximum convergence ratio

At the maximum rating of the powerplant, it is desirable to enlarge the exit throat sectional area so as to obtain a maximum thrust ; the air flow through the engine increases ; as a counterpart, the passage velocities through the combustion chamber become higher : as a result, the head losses increase.

For the performance characteristics calculations we have admitted that the convergence ratio (exit nozzle throat cross-sectional area/combustion chamber inner cross-sectional area) should not exceed 0.75. This value has already been successfully tested on the NORD-AVIATION

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ramjet-powered missiles and on the GRIFFON aircraft powered by a turbo-ramjet combination engine.

7.2 - Simple-convergent configuration

In subsonic and transonic flight, up to Mach 1.3, the performance characteristics are calculated with the exit nozzle in the simple-convergent configuration. To take into account a constriction of the jet we admit that within the exit section prevails an overpressure p_9 / p_o defined by

$$\frac{p_9 - p_o}{\frac{\gamma_o}{2} p_o \; M_o^2} = 0.1$$

from which

$$p_9 / p_o = 1 + 0.1 \; \frac{\gamma_o}{2} \; M_o^2$$

7.3 - Convergent-divergent configuration

In supersonic flight, for flight Mach numbers greater than 1.3, the exit nozzle is set into the "convergent-divergent" configuration.

The performance characteristics are calculated with the assumption that the gases expand down to atmospheric pressure, with the following hypotheses :

- isentropic expansion
- chemical equilibrium reached in every section of the nozzle.

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In order to take into consideration, in the aggregate, the losses due to friction in the nozzle, to divergence of the exit jet, and to partial dissociation, we introduce a nozzle coefficient φ. For flight Mach numbers greater than 1.3, this coefficient is set constant and equal to 0.98.

The influence of this coefficient over the performance characteristics is detailed in Vol. 1 - SPECIFICATIONS AND PERFORMANCE.

8 - GEOMETRICAL DATA

The basic cross-sectional areas of the combination engine adopted for the calculation of performance characteristics, are those which were defined in the research executed under cover of the previous contract AF 61 (052)-670 : TURBOFAN RAMJET ENGINE STUDIES (Vol. 3.1 - GENERAL DIMENSIONS).

The mixer throat cross-section area, A''_3, is equal to 3.6 sq.ft.

Cross-sectional area of the combination engine combustion chamber, A_7 , is equal to 12.6 sq.ft.

Cross-sectional area A''_4 , which is the difference between the combustion chamber cross-section and the external cross-section A'_4 of the outer casing at the level of the turbofan turbines, is equal to 7.5 sq.ft.

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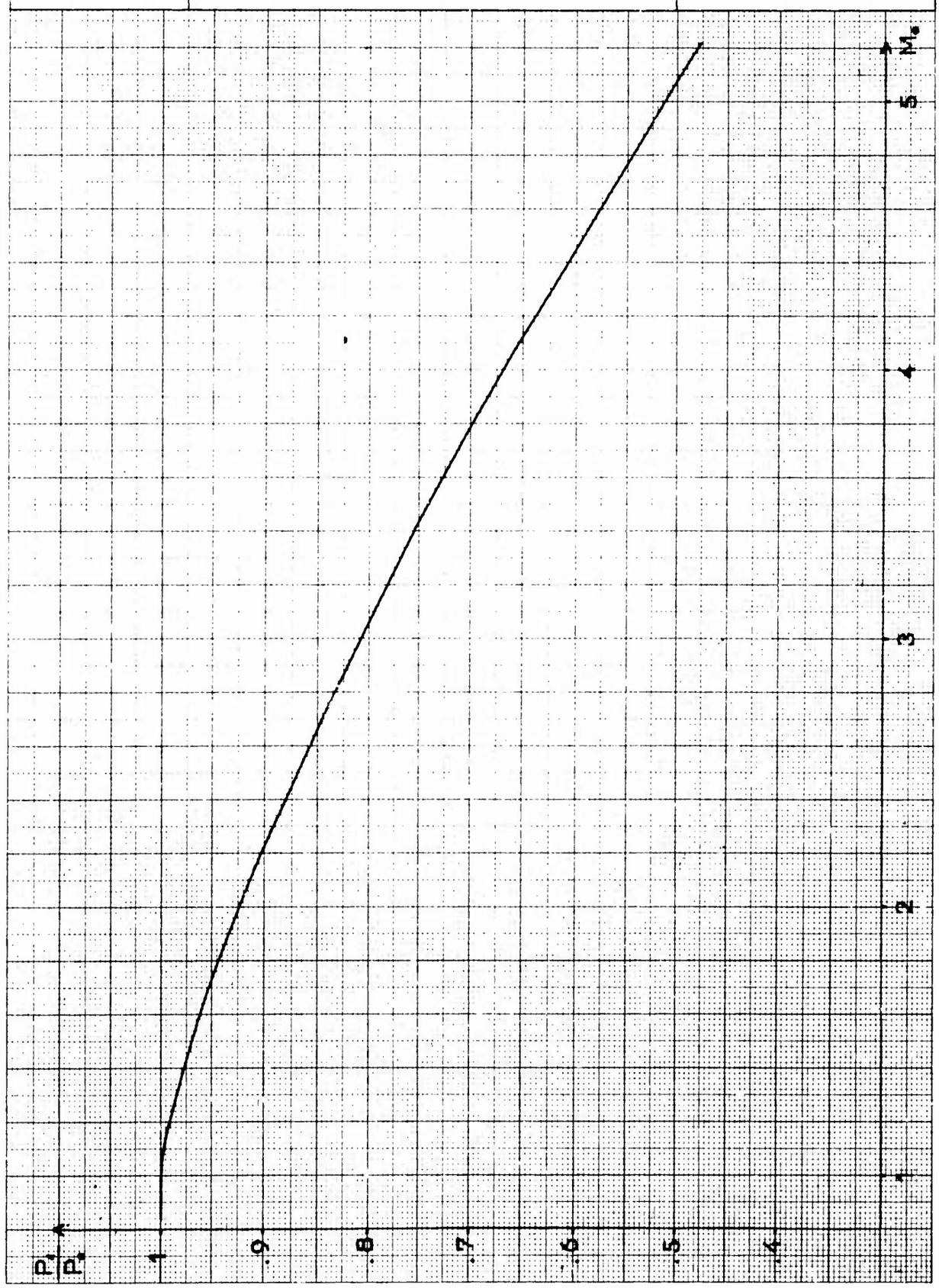
Nord Aviation	AIR INLET PRESSURE RECOVERY	5151/NIOBE IV/33/2
		Figure 1



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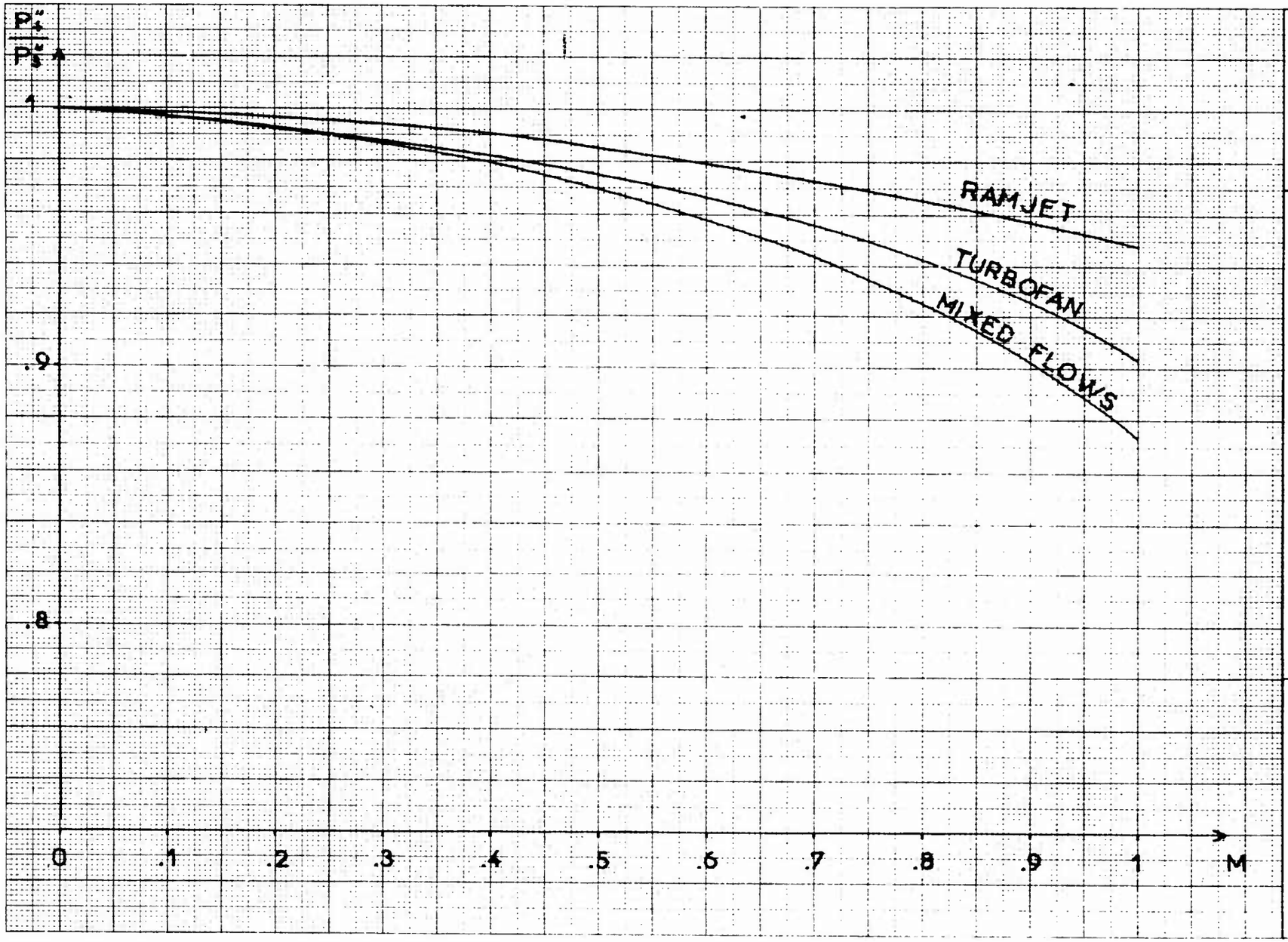


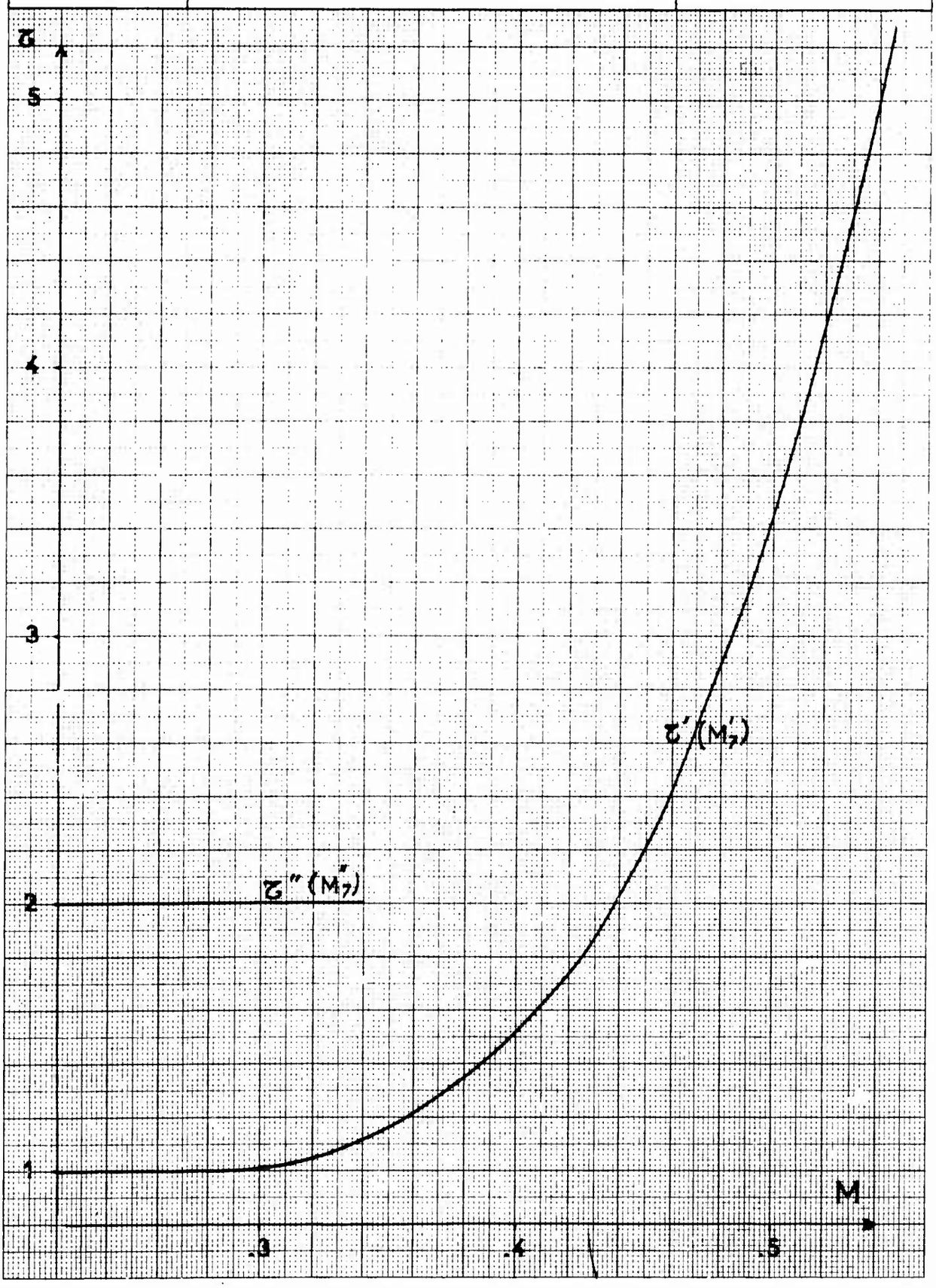
Nord-Aviation

HEAD LOSSES IN THE DIFFUSER

5151/NIOBE IV/33/2

Figure 2

Nord-Aviation	FLAME HOLDER DRAG COEFFICIENTS	5151/NIOBE IV/33/Z
		Figure 3



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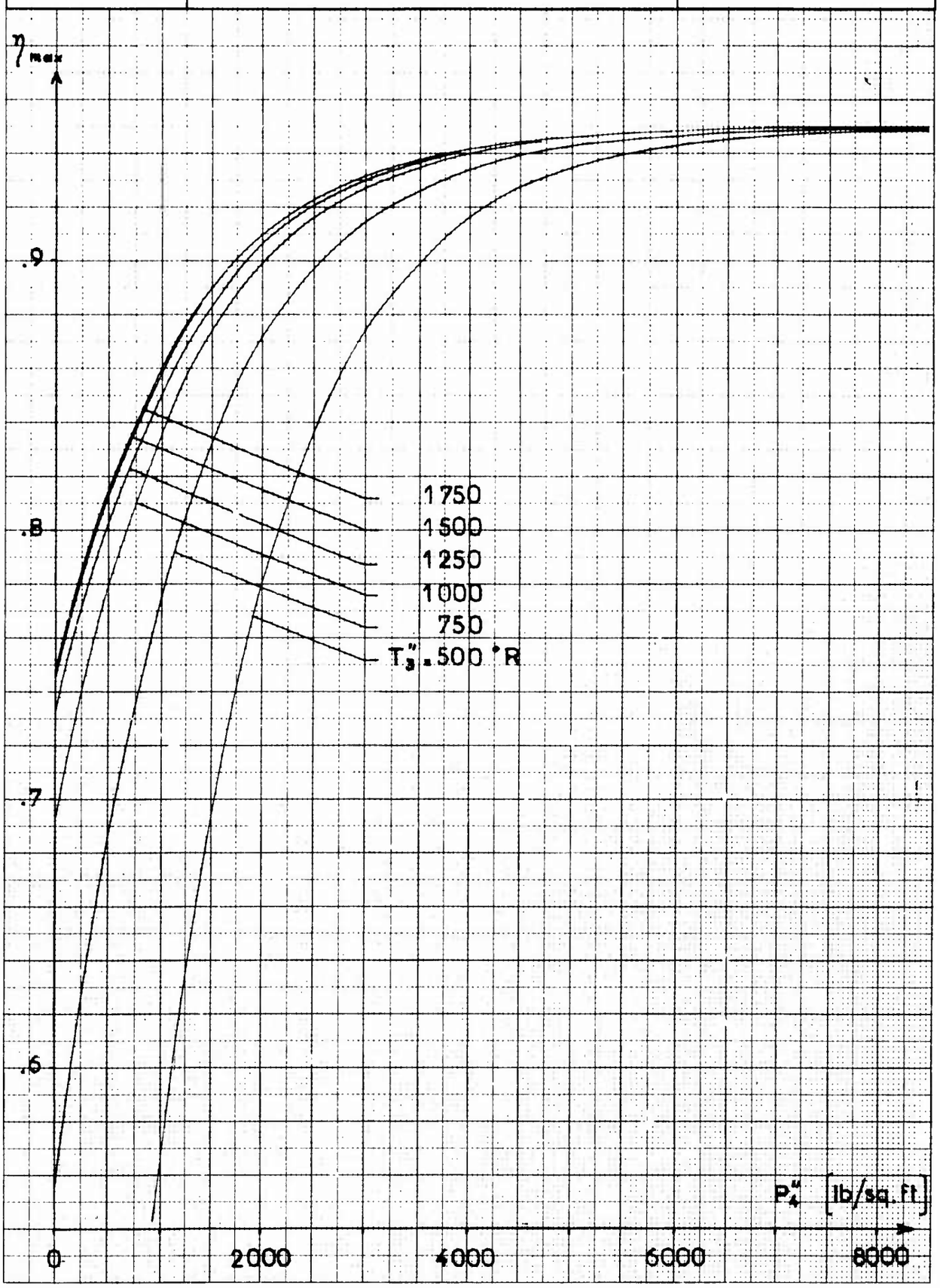
Nord-Aviation	ANNULAR COMBUSTION SYSTEM MAXIMUM COMBUSTION EFFICIENCY	5151/NIOBE IV/33/Z Figure 4



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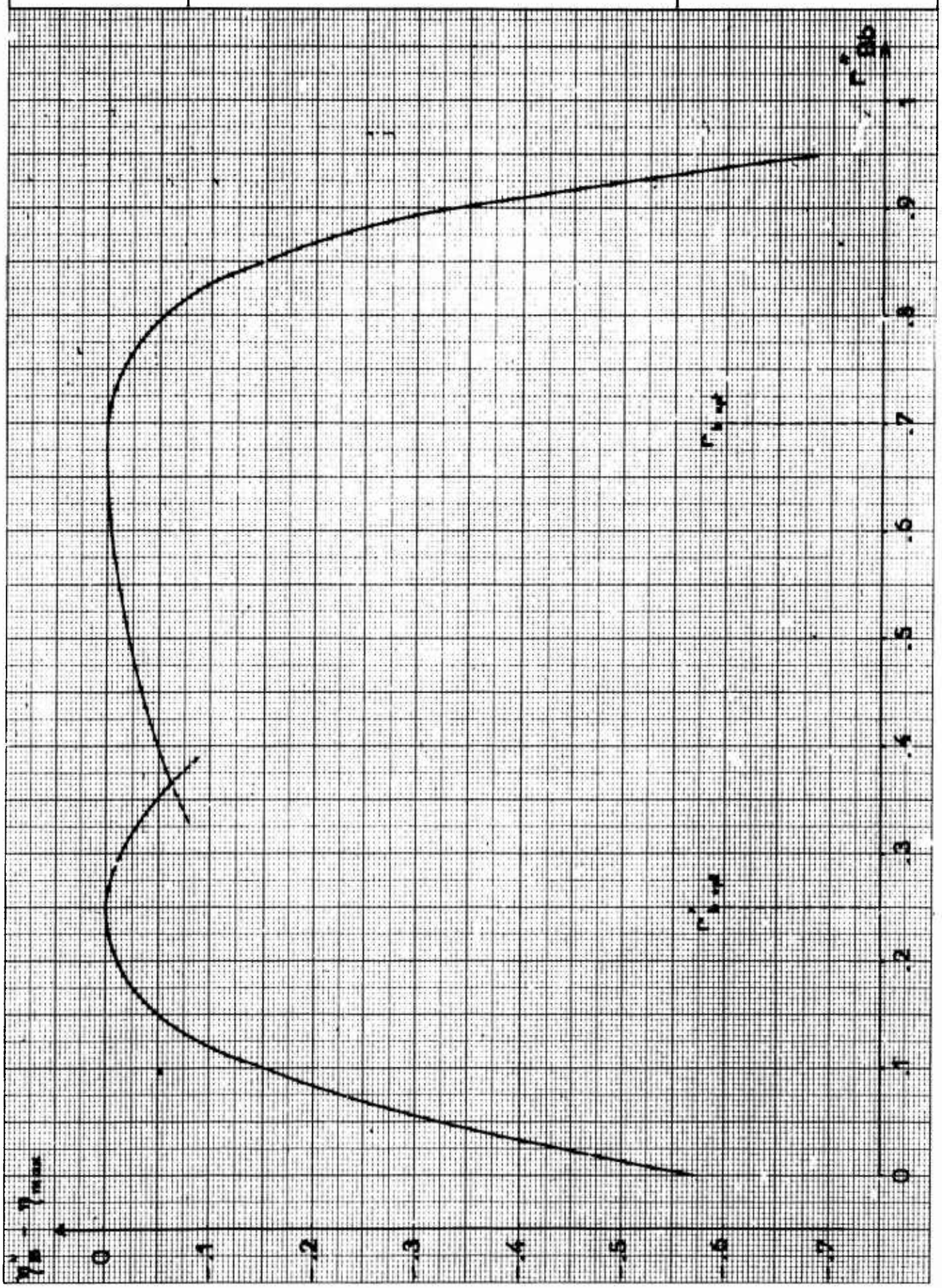
Nord-Aviation	ANNULAR COMBUSTION SYSTEM COMBUSTION EFFICIENCY	5151/NIOBE IV/33/Z Figure 5



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13. ABSTRACT

Data are presented for calculations relating to the performance characteristics of the turbofan-ramjet combination engine. The data fall into two categories:

1. The geometric and thermodynamic characteristics of the SNECMA TF 106 turbofan as related to the turbofan-ramjet combination engine

2. The numerical values of the various parameters, coefficients, and functions defining the efficiencies of the different parts of the engine as well as the geometric characteristics pertaining only to the combination engine.

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