AD-A046 225 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 21/5
CALCULATING TEMPERATURE OF TURBINE BLADES WITH EFFUSION COOLING--ETC(U)
MAY 77 V I LOKAY, S G DEZIDERYEV

UNCLASSIFIED FTD-ID(RS)I-0762-77 NL

| OF |
AD
A046 225

END
DATE
FILMED
12-77
DDC

FTD-ID(RS)I-0762-77

(1)

FOREIGN TECHNOLOGY DIVISION

CALCULATING TEMPERATURE OF TURBINE BLADES WITH
EFFUSION COOLING

by

V. I. Lokay, S. G. Dezider'yev

EDITED TRANSLATION

FTD-ID(RS)I-0762-77 20 May 1977

MICROFICHE NR: FTD-77-C-000600

CALCULATING TEMPERATURE OF TURBINE BLADES WITH EFFUSION COOLING

By: V. I. Lokay, S. G. Dezider'yev

English pages: 9

Source: Trudy Kazanskiy Ordena Trudovogo Krasnogo Znameni Aviatsionnyy Institut, Kazan', No. 101, 1968, PP. 15-20

Country of origin: USSR
Translated by: Marilyn Olaechea
Requester: FTD/PDRS

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	*α*	Nu	Ν	ν
Beta	Β	β		Xi	Ξ	ξ
Gamma	Γ	γ		Omicron	Ο	ο
Delta	Δ	δ		Pi	Π	π
Epsilon	Ε	ε	ϵ	Rho	Ρ	ρ ϱ
Zeta	Ζ	ζ		Sigma	Σ	σ ς
Eta	Η	η		Tau	Τ	τ
Theta	Θ	θ	ϑ	Upsilon	Τ	υ
Iota	Ι	ι		Phi	Φ	φ ϕ
Kappa	Κ	ϰ κ	*ϰ*	Chi	Χ	χ
Lambda	Λ	λ		Psi	Ψ	ψ
Mu	Μ	μ		Omega	Ω	ω

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

CALCULATING TEMPERATURE OF TURBINE BLADES WITH EFFUSION COOLING

V. I. Lokay, S. G. Dezider'yev

Calculations show that when the parameters of the working fluid are sufficiently high, internal convective cooling of turbine blades is ineffective. The temperature of the outer surface of the blade remains inadmissibly high and the temperature gradient in the sleeve is too great.

It is for this reason that the so called effusion method of cooling the flow part [3] has been the subject of ever increasing attention. The outer wall of the turbine blade (sleeve) is made in this case of a permeable sheet material.

The low relative curvature of the convex and concave parts of the blade profile make it possible to analyze them approximately as plates. The inlet and outlet edges can be regarded as the walls of cylinders with a well known approximation. Presented in the present work are the analytical relationships for calculating the distribution of temperatures over the thickness of porous blade walls under boundary conditions of the third type. In contrast to [1] and [2], where the calculation is made under the assumption that the temperatures of the coolant and the walls are equal, this limitation has been removed in the present article, increasing its accuracy [4].

Temperature Distribution with Respect to Wall Thickness on Convex and Concave Portions of the Profile (Flat Wall)

The calculation scheme is shown in Fig. 1. Under stationary conditions for a wall element of length dx

$$q_{x+dx}-q_x-dq_0=0, \tag{1}$$

where

$$q_x = \lambda \bar{f}_{\text{cк}} \left(\frac{dt}{dx}\right)_x; \quad (2)$$

$$q_{x+dx} = -\lambda \bar{f}_{\text{cк}} \left(\frac{dt}{dx}\right)_{x+dx}; \quad (3)$$

$$dq_0 = \alpha_v (t - t_0)_x \cdot dx. \quad (4)$$

Here $\bar{f}_{\text{cк}} = \frac{f_{\text{cк}}}{f}$; f - the area of the space surface of the wall; $f_{\text{cк}}$ - area of cross section of wall frame normal to the stream of fluid; λ, α_v - heat conductivity of wall and volumetric heat exchange coefficient averaged over thickness; t, t_0 - temperature of wall and coolant in studied sections.

The porosity of the material is usually characterized by the quantity

$$\Pi = \frac{\rho_c - \rho_n}{\rho_c} = 1 - \bar{\rho}, \quad (5)$$

where ρ_c, ρ_n is the density of the material without pores (solid) and with pores, respectively.

When the structure of the porous material is homogeneous, on the basis of (5) we easily come to the conclusion that numerically

$$f_{\text{cк}} = 1 - \Pi = \bar{\rho}. \quad (6)$$

Considering equality (6), from expression (1) we find

$$\lambda\bar{\rho}\frac{d^2t}{dx^2}-\alpha_v(t-t_0)=0. \quad (7)$$

On the other hand, according to the equation of enthalpies

$$dq_0=G_0C_{p0}dt_0, \quad (8)$$

where G_0 is the mass flow rate of the coolant inside the plate (f = 1 m^2); C_{p0} - the average isobaric heat capacity of the coolant with respect to wall thickness.

By comparing (4) and (8), we find

$$G_0C_{p0}\,dt_0=\alpha_v(t-t_0)\,dx \quad (9)$$

or

$$\frac{dt_0}{dx}=\frac{\alpha_v}{G_0C_{p0}}. \quad (10)$$

By jointly solving (7) and (10), after certain simple mathematical transformations and a shift to dimensionless variables

$\bar{x}=\frac{x}{\delta}$ and $\theta=\frac{t}{t_r^c}$, we finally get

$$\frac{d^3\theta}{d\bar{x}^3}+k_1\frac{d^2\theta}{d\bar{x}^2}-k_2\frac{d\theta}{d\bar{x}}=0. \quad (11)$$

Here $k_1=\frac{\alpha_v\delta}{G_0C_{p0}}$; $k_2=\frac{\alpha_v\delta^2}{\lambda\bar{\rho}}$.

The solution to equation (11) takes the form of

$$\theta=C_1e^{a_1\bar{x}}+C_2e^{a_2\bar{x}}+C_3e^{a_3\bar{x}}, \quad (12)$$

where a_1, a_2, and a_3 are the roots of the characteristic equation

$$a^3+k_1a^2-k_2a=0. \quad (13)$$

From (13) it follows directly that $a_1 = 0$,

$$a_{2,3}=-\frac{k_1}{2}\pm\sqrt{\frac{k_1^2}{4}+k_2}.$$

Thus, we finally get

$$\theta=C_1+C_2e^{a_2\bar{x}}+C_3e^{a_3\bar{x}}. \quad (14)$$

Integration constants C_1, C_2, and C_3 are found from the boundary conditions of the 3rd type (symbols shown in Fig. 1):

when $\bar{x}=0$

$$\alpha_{c}(\theta'-\theta_{0\infty})=\frac{\lambda\bar{\rho}}{\delta}\left(\frac{d\theta}{d\bar{x}}\right)_{\bar{x}=0}, \quad (15)$$

where

$$\theta'=\frac{t'}{t_r^*};\ \theta_{0\infty}=\frac{t_{0\infty}}{t_r^*};$$

when $\bar{x}=1$

$$\alpha_r(1-\theta'')=\frac{\lambda\bar{\rho}}{\delta}\left(\frac{d\theta}{d\bar{x}}\right)_{\bar{x}=1}, \quad (16)$$

where $\theta''=\frac{t''}{t_r^*}$;

when $\bar{x}=0$, **from equation (7) in dimensionless form**

$$\left(\frac{d^2\theta}{d\bar{x}^2}\right)_{\bar{x}=0}-\frac{\alpha v\delta^2}{\lambda\bar{\rho}}(\theta'-\theta_0')=0, \quad (17)$$

where $\theta_0'=\frac{t_0'}{t_r^*}$.

Thus, we find

$$C_1=\frac{\Delta C_1}{\Delta};\ C_2=\frac{\Delta C_2}{\Delta};\ C_3=\frac{\Delta C_3}{\Delta},$$

where

$$\Delta C_1=\begin{vmatrix}\theta_{0\infty} & (1-b_0a_2) & (1-b_0a_3)\\ \theta_r^* & \lvert(1+b_ra_2)e^{a_2}\rvert & \lvert(1+a_3b_r)e^{a_3}\rvert\\ \theta_{\infty} & \left(1-a_2^2\frac{b_v}{d}\right) & \left(1-a_3^2\frac{b_v}{d}\right)\end{vmatrix};$$

$$\Delta C_2=\begin{vmatrix}1 & \theta_{0\infty} & (1-b_0a_3)\\ 1 & \theta_r^* & \lvert(1+a_3b_r)e^{a_3}\rvert\\ 1 & \theta_{0\infty} & \left(1-a_3^2\frac{b_v}{d}\right)\end{vmatrix};$$

$$\Delta C_3 = \begin{vmatrix} 1 & (1-b_0a_2) & \theta_{0\infty} \\ 1 & [(1+a_2b_r)e^{a^2}] & \theta_r^* \\ 1 & \left(1-a^2\frac{b_v}{d}\right) & \theta_{0\infty} \end{vmatrix};$$

$$\Delta = \begin{vmatrix} 1 & (1-b_0a_2) & (1-b_0a_3) \\ 1 & [(1+b_ra_2)e^{a_2}] & [(1+b_ra_3)\cdot e^{a_3}] \\ 1 & \left(1-a_2^2\frac{b_v}{d}\right) & \left(1-a_3^2\frac{b_v}{d}\right) \end{vmatrix}.$$

Here, for the sake of brevity we will designate

$$\frac{\lambda\bar{\rho}}{\alpha_0\delta} = b_0; \quad \frac{\lambda\bar{\rho}}{\alpha_r\delta} = b_r; \quad \frac{\lambda\bar{\rho}}{\alpha_v\delta^2} = b_v; \quad 1 - \frac{\alpha_0}{G_0C_{p_0}} = d.$$

As an example Fig. 2 shows the temperature distribution with respect to wall thickness, calculated by the described method (curve 1). Here point 2 marks the temperature of the outer surface in the case of convective coolant, calculated for the same starting data and flow rate of the coolant. There is a sharp temperature in the case of porous cooling. The dashed line (curve 3) shows the behavior of the temperature in the wall, calculated according to the method of [2] with noticeable temperature distortion. Analysis shows that calculation error here increases as the thermal head between the gas and the coolant increases and also when α_v, δ and λ_{CT} decreases. This increase may reach 10-20o/o [5].

Temperature Distribution with Respect to Wall Thickness in Vicinity of Blade Edges (Cylindrical Wall)

The calculation scheme and the main symbols are shown in Fig. 3. Under the same assumption used earlier from the equation of thermal balance

$$q_{r+dr} - q_r - dq_0 = 0 \qquad (18)$$

we can get

$$\frac{d^3\theta}{d\bar{r}^3} + \xi(\bar{r})\frac{d^2\theta}{d\bar{r}^2} + \zeta(\bar{r})\frac{d\theta}{d\bar{r}} = 0. \qquad (19)$$

Here

$$\bar{r} = \frac{r}{r_r}; \quad \theta = \frac{t}{t_r^*}; \; \xi(\bar{r}) = k_{v1} + \frac{1}{\bar{r}};$$

$$\zeta(\bar{r}) = \frac{k_{v1}}{\bar{r}} - \frac{1}{\bar{r}^2} - k_{v2},$$

where for brevity we designate

$$\frac{a_v r_r^2}{\lambda \bar{\rho}} = k_{v2}\;\; \frac{a_v r_r}{G_0 C_{p_0}} = k_{v1}.$$

Equation (19) determine the temperature distribution in a cylindrical wall cooled by the effusion method.

Received 28 June 1967

BIBLIOGRAPHY

1. Шнейдер П. Инженерные проблемы теплопроводности. М., ИЛ, 1960.
2. Исаченко В. П. и др. Теплопередача. М., „Энергия", 1965.
3. Grootenhuis P. The J. of the RAS, No 578, 1959.
4. Болгарский А. В., Мухачев Г. А., Щукин В. К. Термодинамика и теплопередача. М., „Высшая школа", 1964.
5. Щукин В. К. Температурное состояние пористой стенки при эффузионном охлаждении. „Теплоэнергетика", 1962, № 1.

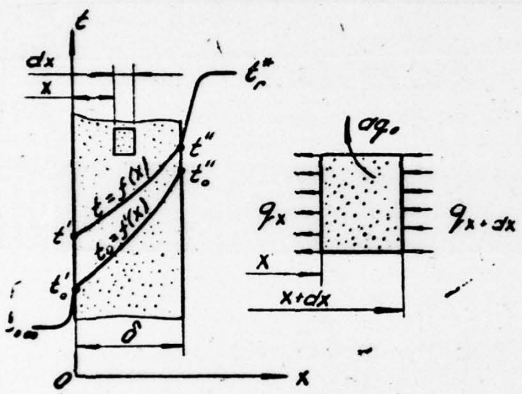

Fig. 1.

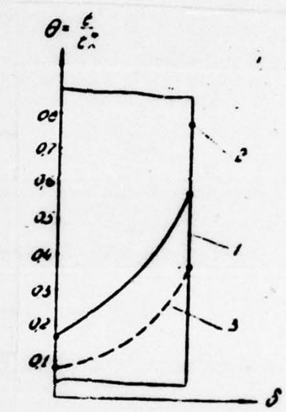

Fig. 2.

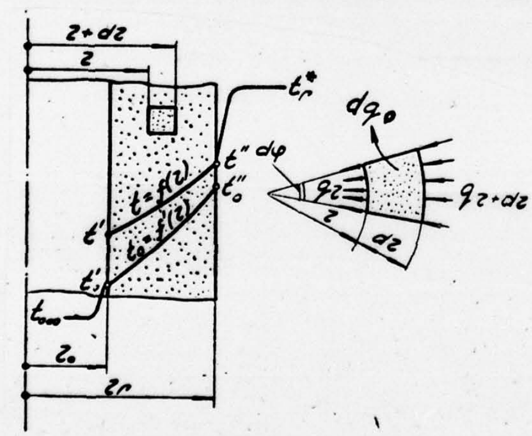

Fig. 3.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FTD-ID(RS)I-0762-77	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CALCULATING TEMPERATURE OF TURBINE BLADES WITH EFFUSION COOLING		5. TYPE OF REPORT & PERIOD COVERED Translation 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) V. I. Lokay, S. G. Dezider'yev		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Foreign Technology Division Air Force Systems Command U. S. Air Firce		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 1968 13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) 21		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION		MICROFICHE
A205	DMATC	1
A210	DMAAC	2
B344	DIA/RDS-3C	8
C043	USAMIIA	1
C509	BALLISTIC RES LABS	1
C510	AIR MOBILITY R&D LAB/FIO	1
C513	PICATINNY ARSENAL	1
C535	AVIATION SYS COMD	1
C557	USAIIC	1
C591	FSTC	5
C619	MIA REDSTONE	1
D008	NISC	1
H300	USAICE (USAREUR)	1
P005	ERDA	1
P055	CIA/CRS/ADD/SD	1
NAVORDSTA (50L)		1
NAVWPNSCEN (Code 121)		1
NASA/KSI		1
[redacted]		[redacted]
AFIT/LD		1

ORGANIZATION		MICROFICHE
E053	AF/INAKA	1
E017	AF/ RDXTR-W	1
E404	AEDC	1
E408	AFWL	1
E410	ADTC	1
E413	ESD	2
	FTD	
	CCN	1
	ETID	3
	NIA/PHS	1
	NICD	5