N95- 23427

GGOT TOTAL PRESSURE LOSS CONTROL CONCEPT EVALUATION

1995 117007

R. F. BLUMENTHAL
AEROJET PROPULSION DIVISION
SACRAMENTO, CA

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Total pressure loss is one of the most important parameters in the design of a turbine. This parameter effects not only the turbine performance, but consequently the engine power balance and engine performance. Computational Fluid Dynamics (CFD) can be an effective tool in predicting turbine total pressure loss, and also for performing sensitivity studies to achieve an optimal design with respect to pressure loss. In the present study, the AEROVISC code was used to predict the total pressure loss in the Turbine Technology Team Gas Generator Oxidizer Turbine (GGOT).

The objectives in this study are two-fold. It is first necessary to determine an optimal methodology in predicting total pressure loss. The type of grid, grid density and distribution are parameters which may effect the loss prediction. Also, the effect of using a standard K-ε turbulence model with wall functions versus a two-layer turbulence model needs to be investigated. The use of grid embedding to resolve areas with high flow gradients needs to be explored. The second objective of the study is to apply the optimal methodology toward evaluating different tip leakage control concepts.

The approach taken in this study was as follows:

1) A nominal baseline case was run (baseline grid with standard wall functions)

   a) Grid parametrics were performed on grid density

   b) Grid embedding was applied to the rotor leading and trailing edges, and in the tip region.

   c) Evaluation of a two-layer turbulence model (in progress)

Each of the above cases were assessed in terms of total pressure loss in comparison with the baseline case, and in terms of the difference in secondary flow resolution in comparison with the baseline case.

2) The optimal methodology from Step 1 is applied towards evaluating different tip leakage control concepts which will include

   a) Hollow rotor

   b) Hollow rotor with partitions (labyrinth seal approach)

   c) Hollow rotor with partitions and suction-side rotor slots (to reduce fluid impingement angle)

As this work is still in progress, conclusions are not available at this time.

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GGOT TOTAL PRESSURE LOSS CONTROL CONCEPT EVALUATION

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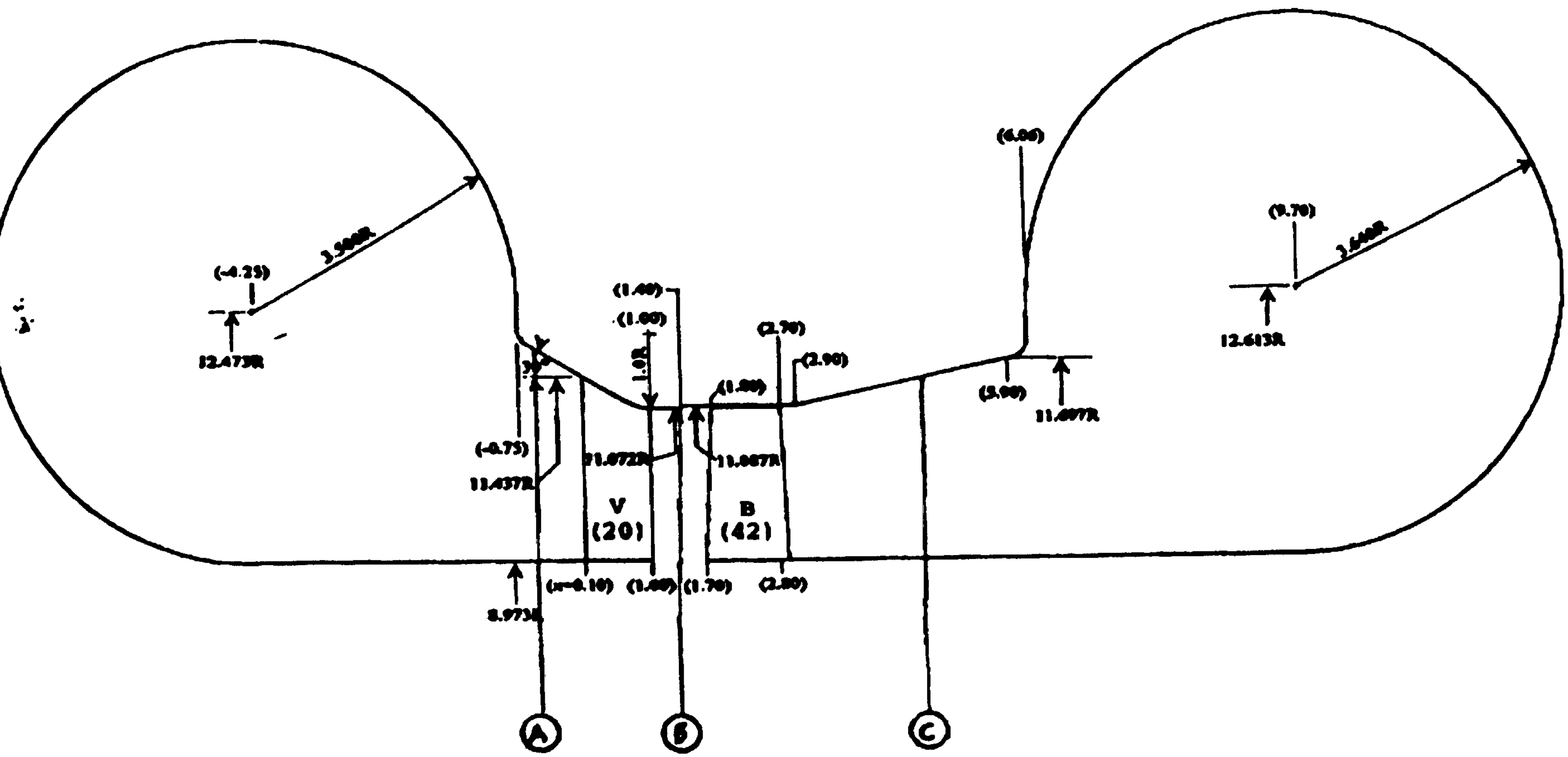
APRIL 22, 1993

OXIDIZER TURBINE BASELINE DESIGN

Full Scale Turbine Flowpath



Axial Location - ( )

A STATION LETTER

GGOT TOTAL PRESSURE LOSS CONTROL CONCEPT EVALUATION

OBJECTIVE : EVALUATE TIP LEAKAGE CONTROL CONCEPTS WHICH REDUCE TIP LEAKAGE AND TOTAL PRESSURE LOSS

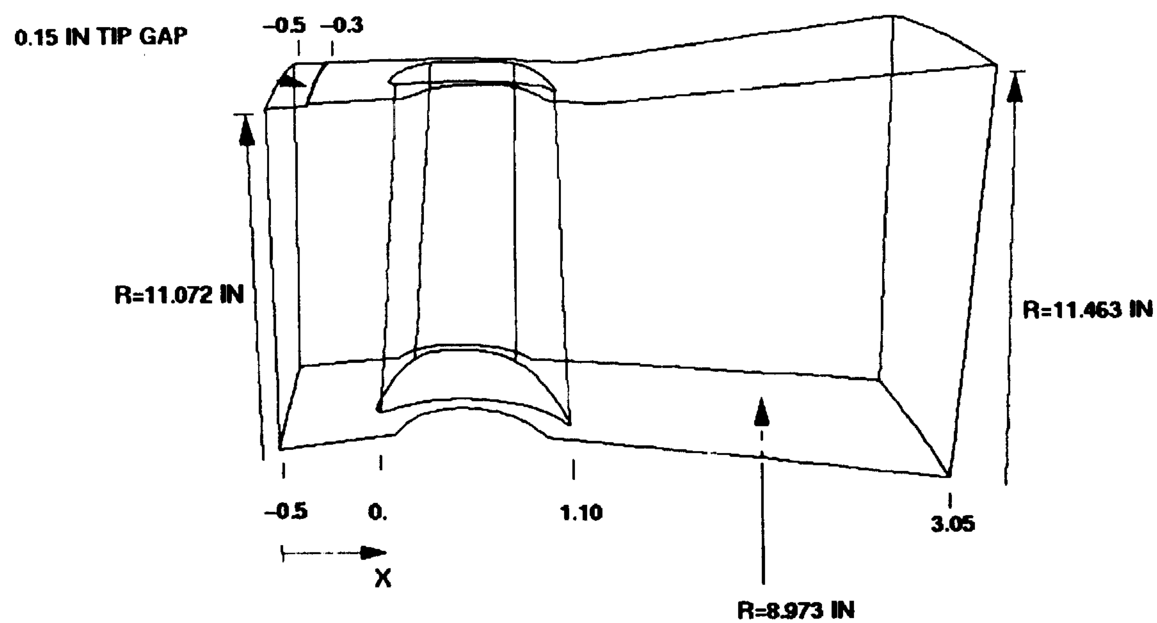
APPROACH : 1.) PERFORM GRID DEPENDENCY STUDY

RUN NOMINAL BASELINE CASE WITH BASELINE GRID USING AEROVISC CODE AND STANDARD LOG–LAW WALL FUNCTION

a.) PERFORM GRID PARAMETERICS ON GRID DENSITY
b.) EVALUATE MERITS OF GRID EMBEDDING
c.) EVALUATE TWO–LAYER TURBULENCE MODEL

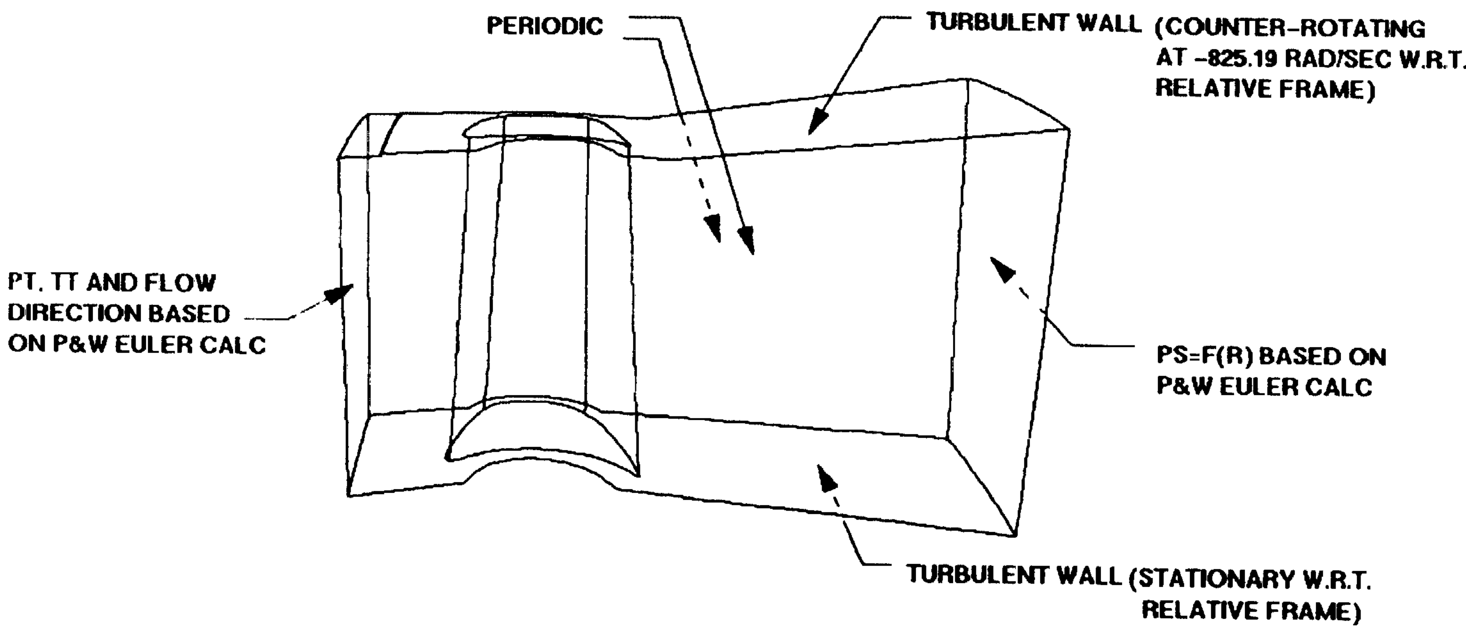
2.) EVALUATE TIP TREATMENT CONCEPTS , INCORPORATING OPTIMAL METHODOLOGY/PROCEDURE FROM STEP 1

GGOT ROTOR CFD MODEL



GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

APPLIED BOUNDARY CONDITIONS



GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID PARAMETRIC APPROACH AND RESULTS

- BASELINE GGOT ROTOR GRID (82 x 41 x 24 w/ 5 GRIDS IN TIP GAP RADIAL DIRECTION)
- GRID PARAMETERICS PERFORMED BY INCREASING GRID COUNT UNIFORMLY IN EACH PARAMETRIC DIRECTION (AXIAL, CIRCUMFERENTIAL, RADIAL). THREE CASES IN EACH DIRECTION WERE RUN, FOR A TOTAL OF TEN CASES (INCLUDING THE BASELINE).
- ALL CASES WERE RUN UNTIL A SIMILAR CONVERGENCE LEVEL WAS ACHIEVED

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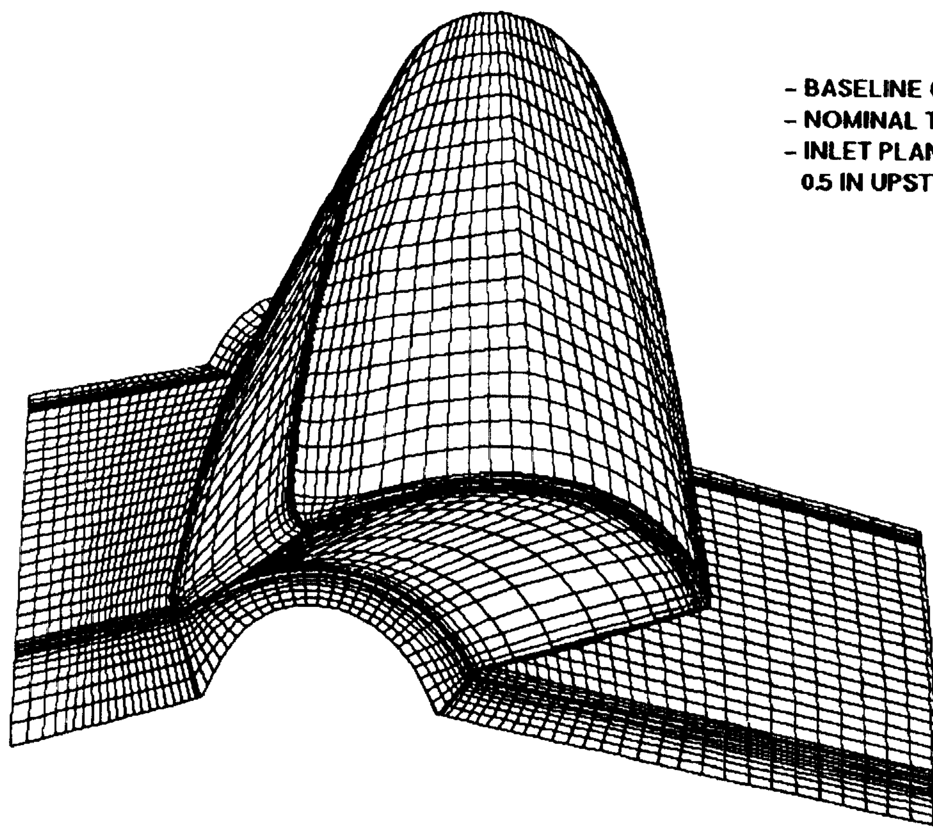
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

BASELINE ROTOR GRID



- BASELINE GRID (82 x 41 x 24)
- NOMINAL TIP GAP=0.015 IN
- INLET PLANE AXIAL LOCATION 0.5 IN UPSTREAM OF LEADING EDGE

GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID PARAMETRIC APPROACH AND RESULTS

	CASE	I-DIR	J-DIR	K-DIR	TIP GAP	TOTAL
	BASELINE	82	41	24	5	80688
AXIAL DIR (I)	CASE 1A	106	41	24	5	104304
	CASE 1B	131	41	24	5	128904
	CASE 1C	237	41	24	5	233208
CIRCUM. DIR (J)	CASE 2A	82	53	24	5	104304
	CASE 2B	82	67	24	5	131856
	CASE 2C	82	120	24	5	236160
RADIAL DIR (K)	CASE 3A	82	41	30	6	100860
	CASE 3B	82	41	36	7	121032
	CASE 3C	82	41	72	13	242064

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GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID PARAMETRIC APPROACH AND RESULTS (PRELIMINARY)

CASE	PT REL (INLET) [PSI]	PT REL (EXIT) [PSI]	DPT REL [PSI]	PLOSS= DPT REL/PT REL (INLET)	PLOSS/ PLOSS BASE
BASE	457.498	365.800	91.698	0.2004	1.0000
CASE 1A	459.075	368.364	90.711	0.1976	0.9859
CASE 1B	459.446	368.627	90.819	0.1977	0.9862
CASE 2A	458.853	367.871	90.982	0.1983	0.9893
CASE 2B	458.978	367.607	91.371	0.1991	0.9932
CASE 3A	455.961	367.574	88.387	0.1939	0.9672
CASE 3B	456.026	367.613	88.413	0.1939	0.9673

NOTE: ALL PRESSURES ARE BASED ON MASS-AVERAGED VALUES

EXIT STATIC PRESSURE USED FOR PRELIMINARY PARAMETERICS
BASED ON STATIC PRESSURE SPECIFIED AT ONE NODE IN EXIT PLANE
(PS=215.5 PSI AT CENTER OF EXIT PLANE)

GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID PARAMETRIC APPROACH AND RESULTS

CASE	PT REL (INLET) [PSI]	PT REL (EXIT) [PSI]	DPT REL [PSI]	PLOSS= DPT REL/PT REL (INLET)	PLOSS/ PLOSS BASE
BASE	456.352	375.839	80.513	0.1764	1.0000
CASE 1C	456.987	373.528	83.459	0.1826	1.0351
CASE 2C	456.788	375.805	80.983	0.1773	1.0051
CASE 3C	456.890	376.620	80.270	0.1757	0.9960

NOTE: ALL PRESSURES ARE BASED ON MASS-AVERAGED VALUES
EXIT STATIC PRESSURE BASED ON RADIAL PRESSURE DISTRIBUTION PROVIDED BY P&W FROM EULER CALC

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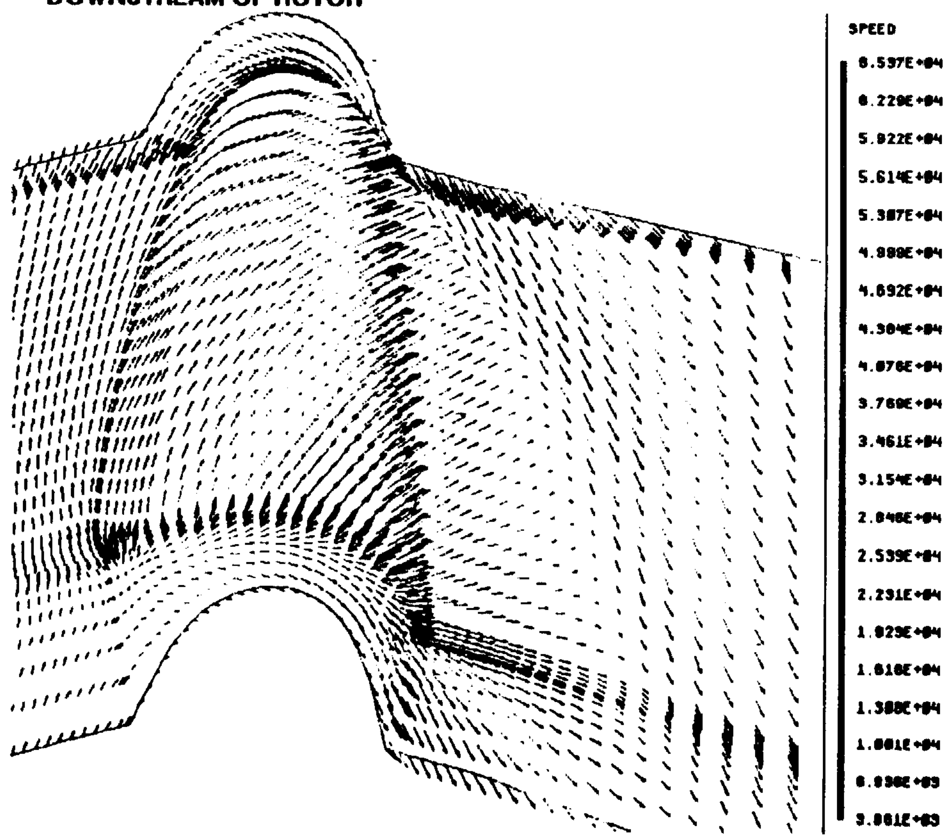
BASELINE RESULTS

VELOCITIES IN MID-GAP REGION (K=22)

HIGH TIP FLOW VELOCITIES COUPLED WITH LARGE IMPINGEMENT ANGLE INFLUENCE MAINSTREAM FLOW AT SOME DISTANCE DOWNSTREAM OF ROTOR



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BASELINE RESULTS

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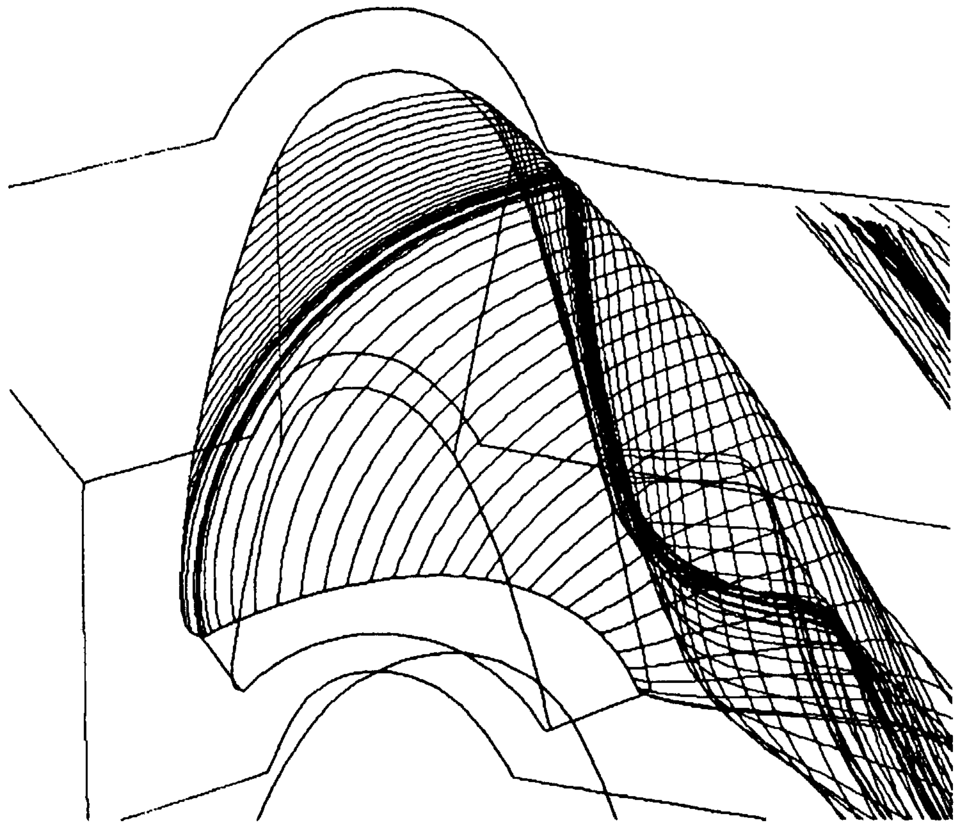
STREAKLINES AT TIP SHOW DEVELOPING PASSAGE VORTEX
(PARTICLES RELEASED IN MID-GAP REGION)



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BASELINE RESULTS

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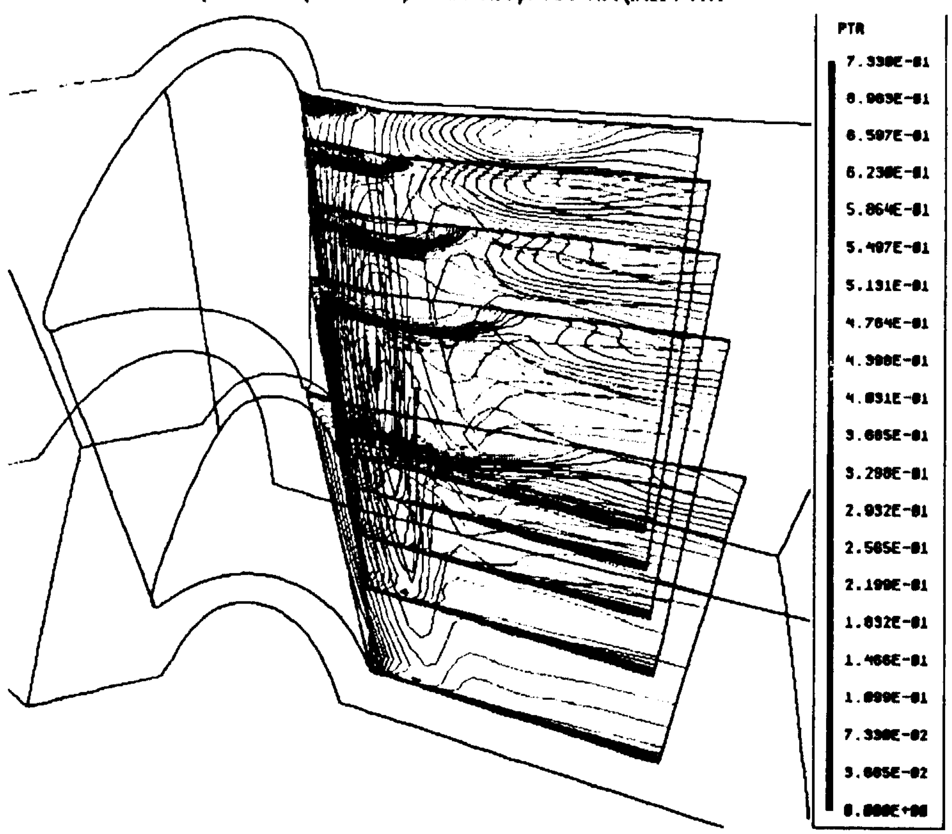
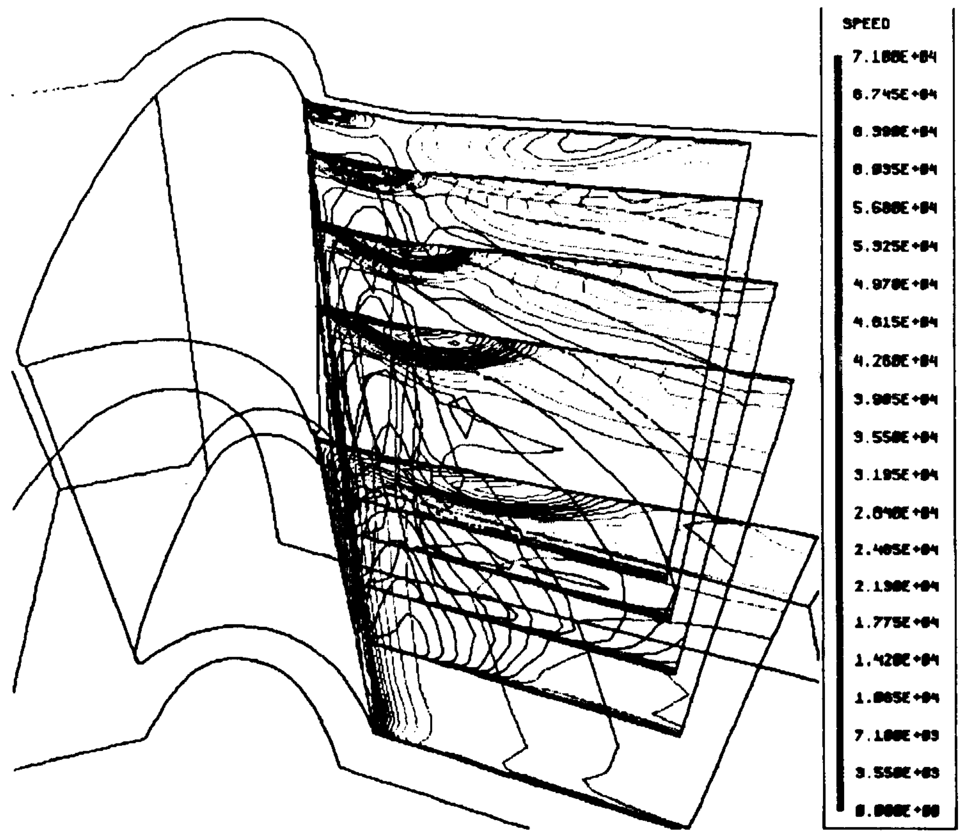
RELATIVE TOTAL PRESSURE LOSS DUE TO TIP GAP FLOW
HIGH LOSS GRADIENT EXISTS NEAR TIP



BASELINE RESULTS

VELOCITY CONTOURS SHOW EFFECT OF TIP LEAKAGE ON MAINSTREAM FLOW
CONSIDERABLE FLOW DECELERATION OCCURS



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GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

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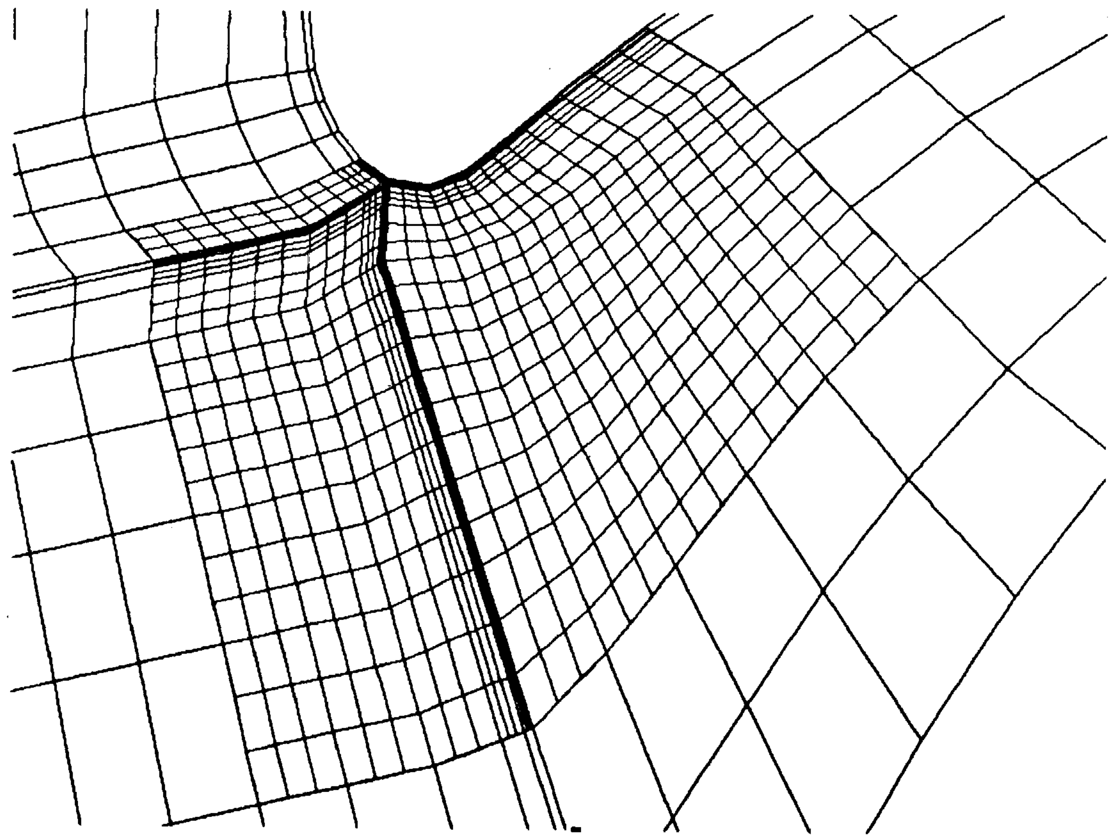
LEADING EDGE EMBEDDING - (31 x 25 x 70)
(EMBEDDED GRIDS EXTEND FROM HUB TO TIP ENDWALL)



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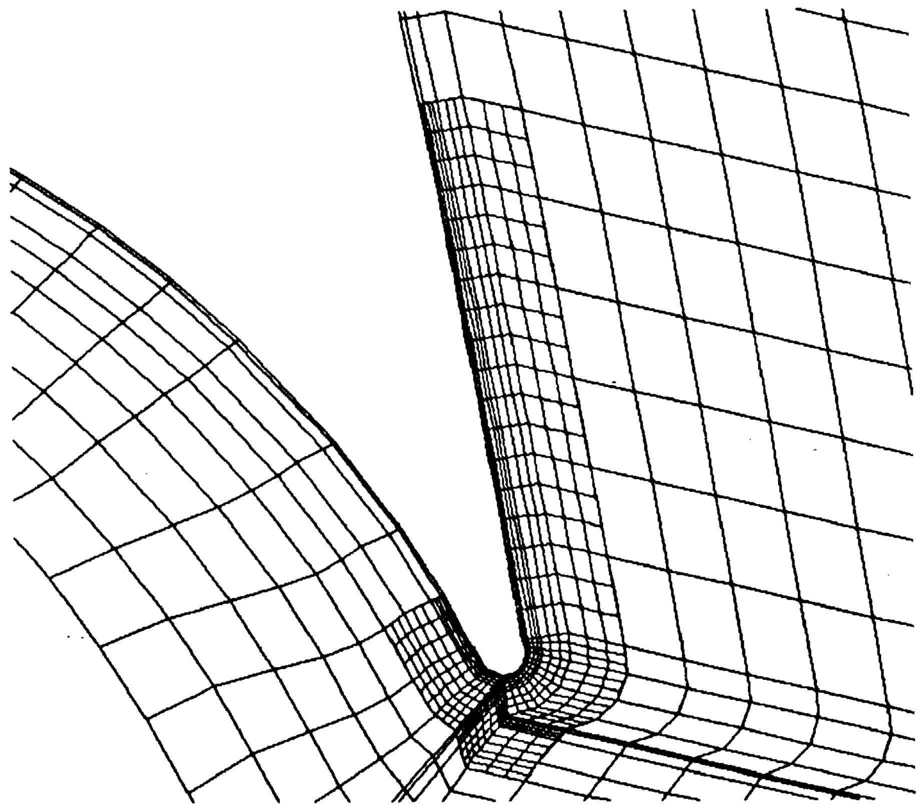
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID EMBEDDING AT TRAILING EDGE (22 x 43 x 70)
(EMBEDDED GRIDS EXTEND FROM HUB TO TIP ENDWALL)



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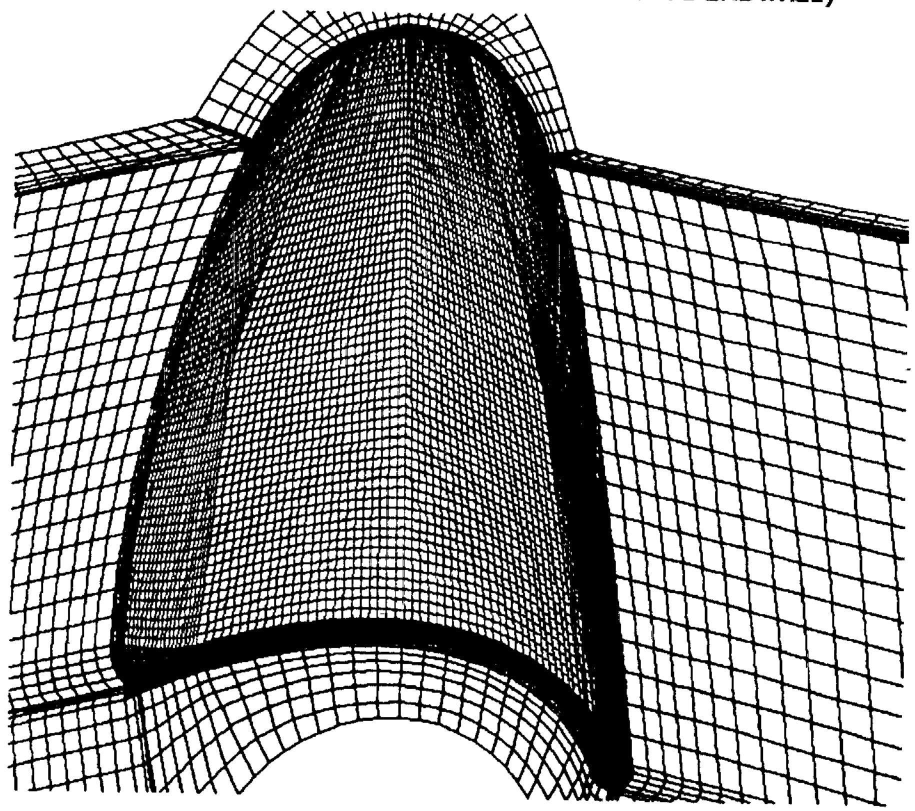
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID EMBEDDING IN THE TIP GAP REGION (103 x 91 x 13)
(EMBEDDED GRIDS EXTEND FROM ROTOR TIP TO ENDWALL)



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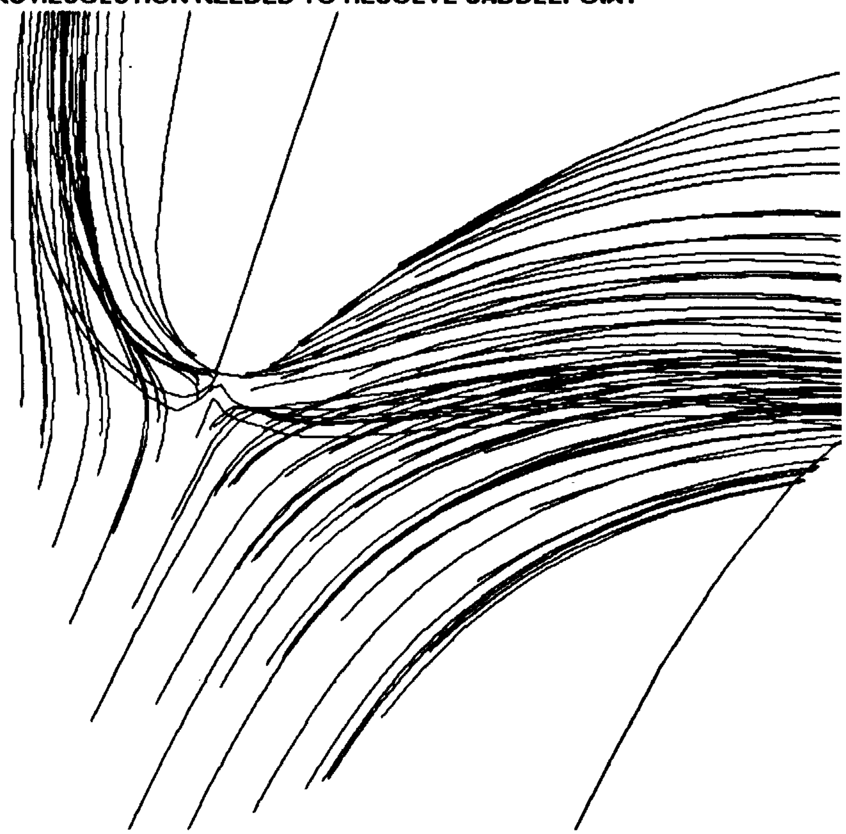
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

BASELINE GRID STREAKLINES NEAR LEADING EDGE (K=2)
GRID LACKS RESOLUTION NEEDED TO RESOLVE SADDLEPOINT



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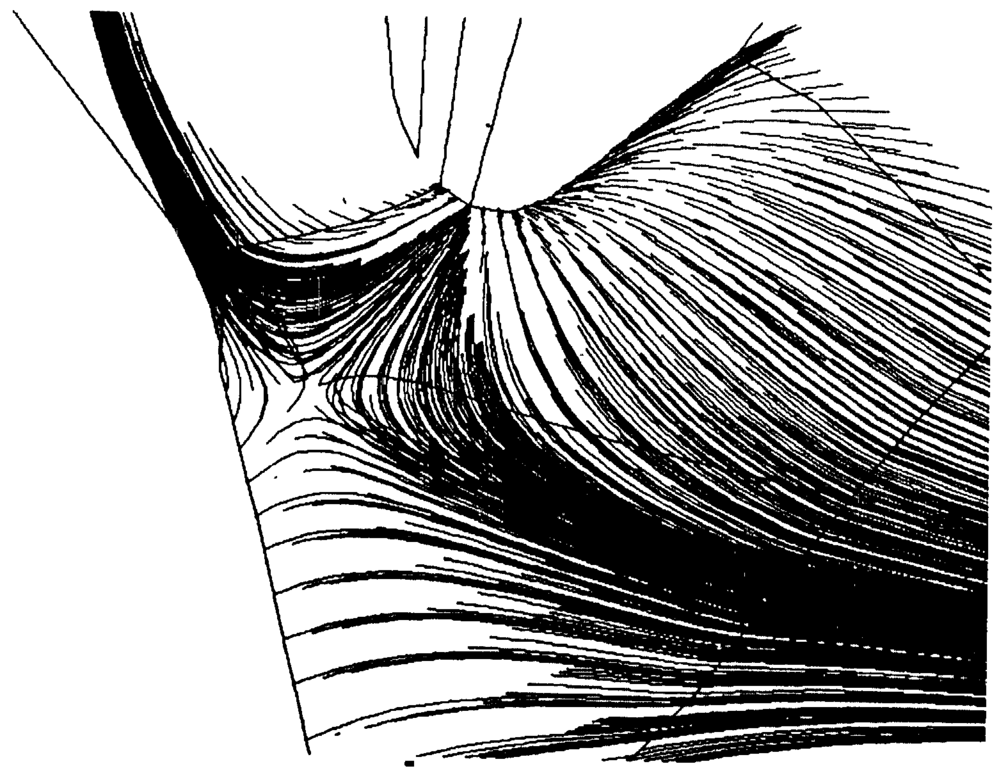
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID EMBEDDING AT LEADING EDGE IS USEFUL IN DEFINING IMPORTANT FLOW FEATURES SUCH AS THE SADDLEPOINT OF THE LIMITING STREAMLINES AT THE HUB



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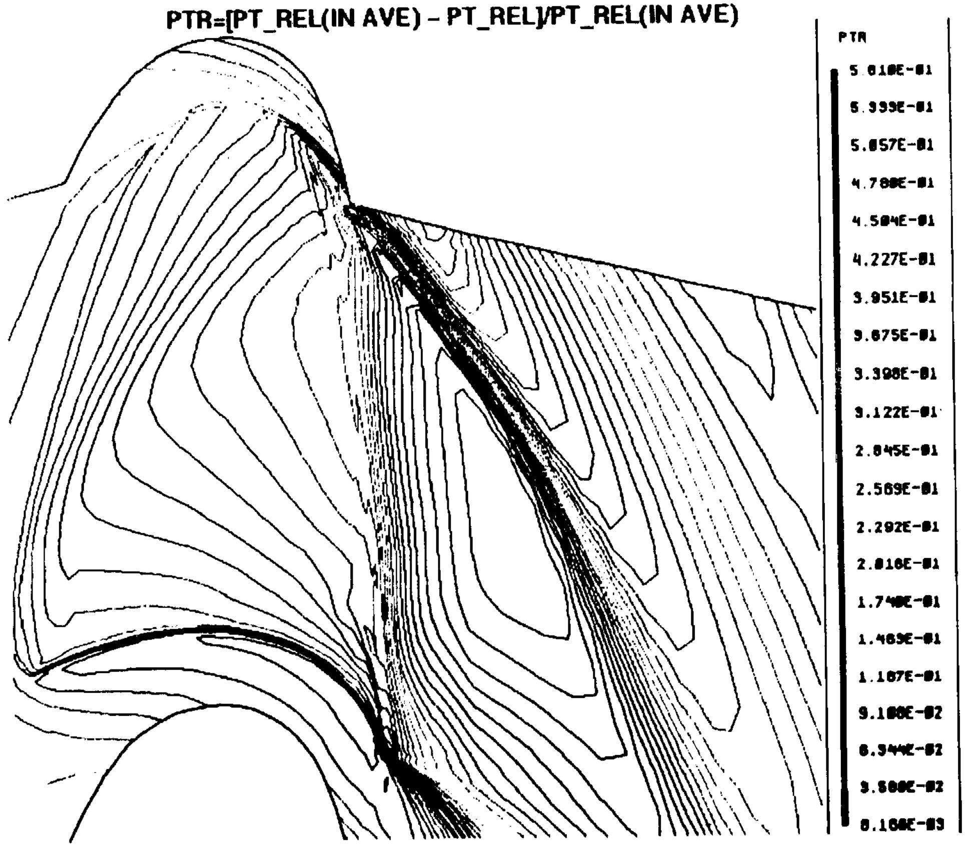
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

BASELINE RESULTS (PRELIMINARY)

RELATIVE TOTAL PRESSURE LOSS AT MIDGAP (K=22)

PTR=[PT_REL(IN AVE) - PT_REL]/PT_REL(IN AVE)



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GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

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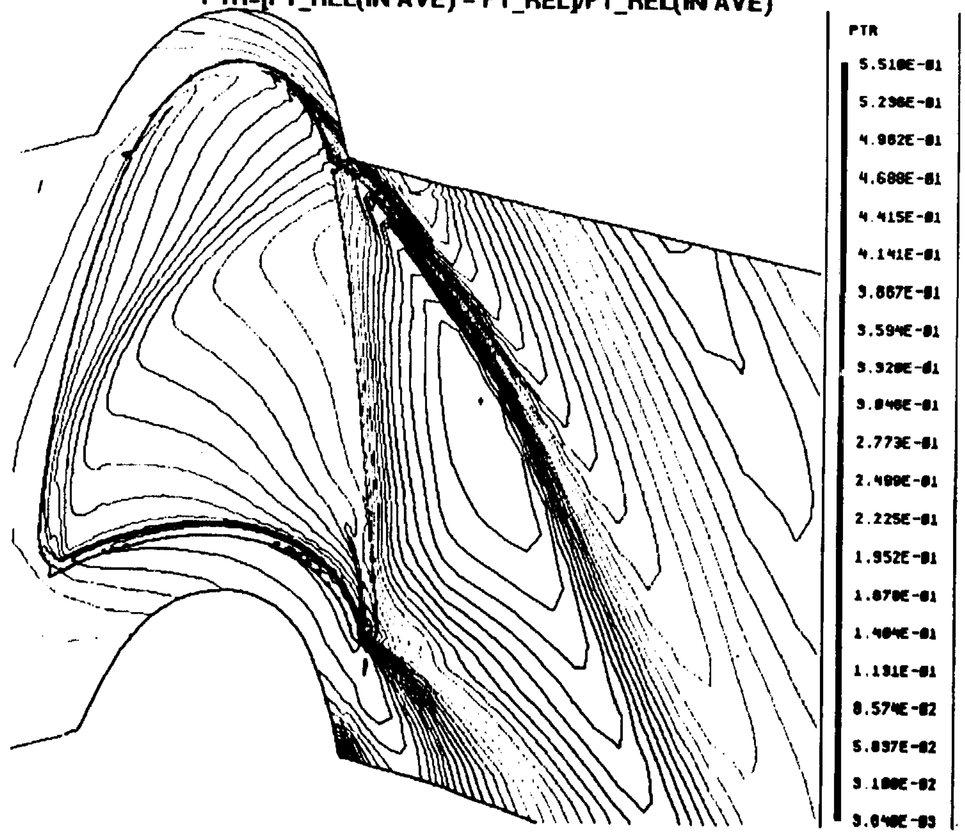
GRID EMBEDDING IN TIP GAP
RELATIVE TOTAL PRESSURE LOSS AT MIDGAP (K=22)
PTR=[PT_REL(IN AVE) - PT_REL]/PT_REL(IN AVE)



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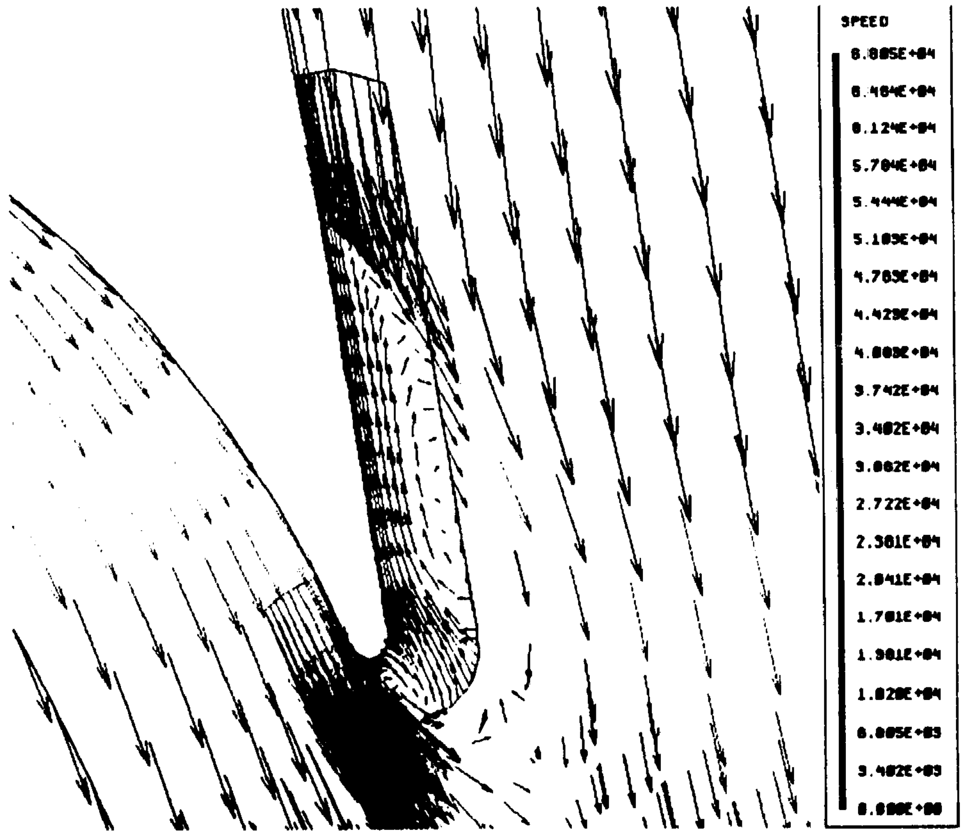
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

TRAILING EDGE GRID EMBEDDING NEAR HUB PLANE (K=2)
EMBEDDING HELPS TO RESOLVE SUCTION SIDE RECIRC



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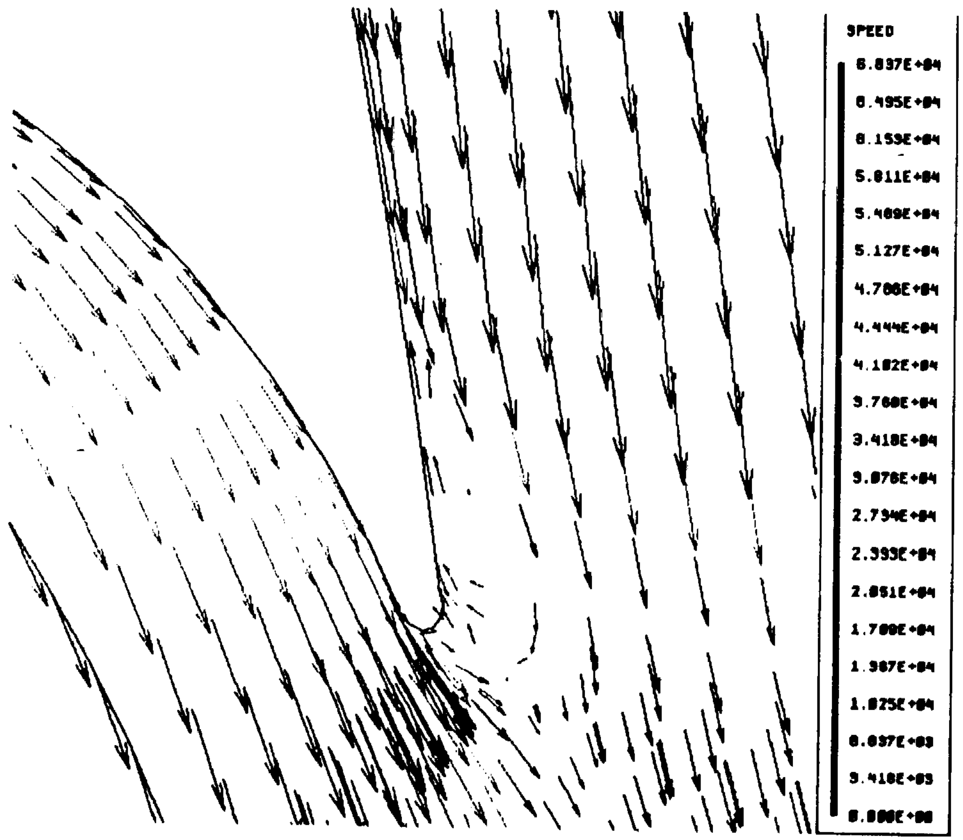
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

BASELINE TRAILING EDGE GRID NEAR HUB PLANE (K=2)



GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

GRID EMBEDDING RESULTS

CASE	PT REL (INLET) [PSI]	PT REL (EXIT) [PSI]	DPT REL [PSI]	PLOSS= DPT REL/PT REL (INLET)	PLOSS/ PLOSS BASE
BASE	457.498	365.800	91.698	0.2004	1.0000
LEADING EDGE	458.104	369.822	88.282	0.1927	0.9614
TIP GAP	458.554	370.401	88.152	0.1922	0.9589
TRAILING EDGE	458.292	369.162	89.130	0.1945	0.9704

NOTE: ALL PRESSURES ARE BASED ON MASS-AVERAGED VALUES

EXIT STATIC PRESSURE USED FOR PRELIMINARY PARAMETERICS BASED ON STATIC PRESSURE SPECIFIED AT ONE NODE IN EXIT PLANE (PS=215.5 PSI AT CENTER OF EXIT PLANE)

GGOT TOTAL PRESSURE LOSS/ -GRID DEPENDENCY STUDY

TWO-LAYER TURBULENCE MODEL

RESULTS PRESENTED THUS FAR ARE BASED ON THE STANDARD K-E TURBULENCE MODEL WHICH EMPLOYS WALL FUNCTIONS TO MODEL THE VISCOUS NEAR-WALL LAYER. THE ADVANTAGE OF THIS APPROACH IS THAT THE WALL FUNCTION ELIMINATES THE NECESSITY OF NUMERICALLY RESOLVING THE LARGE GRADIENTS IN THE THIN NEAR-WALL REGION, THUS CONSERVING COMPUTER RESOURCES. THE DISADVANTAGE IS THAT CERTAIN ASSUMPTIONS MUST BE MADE WHICH MAY NOT BE ACCURATE IN ALL FLOW SITUATIONS, ESPECIALLY WHERE THERE ARE SEPERATED FLOWS.

THE TWO-LAYER TURBULENCE MODEL EMPLOYS THE STANDARD TWO-EQUATION K-E MODEL AWAY FROM THE NEAR WALL REGION, AND USES A ONE-EQUATION TURBULENCE MODEL IN THE NEAR-WALL REGION. IN ORDER TO CORRECTLY APPLY THE TWO-LAYER MODEL, NODES MUST BE CLUSTERED NEAR THE WALLS SUCH THAT THE DAMPING FUNCTIONS fmu-AND feps (USED TO CALCULATE TURBULENT VISCOSITY AND DISSIPATION RATE) CAN BE RESOLVED. IT IS RECOMMENDED THAT AT LEAST 5 NODES BE IN THE REGION YPLUS < 5 AND AT LEAST 15 NODES IN THE REGION YPLUS ≤ 100.

STATUS: MODEL IS CURRENTLY RUNNING. CONVERGENCE DIFFICULTIES HAVE BEEN ENCOUNTERED, PROBABLY RELATED TO HIGH ASPECT RATIOS (~ 25000 AT BLADE SURFACE AT MID-SPAN). SOLUTIONS BEING EXAMINED INCLUDE INCREASING NODE COUNT IN RADIAL DIRECTION, RUNNING CODE IN DOUBLE PRECISION.

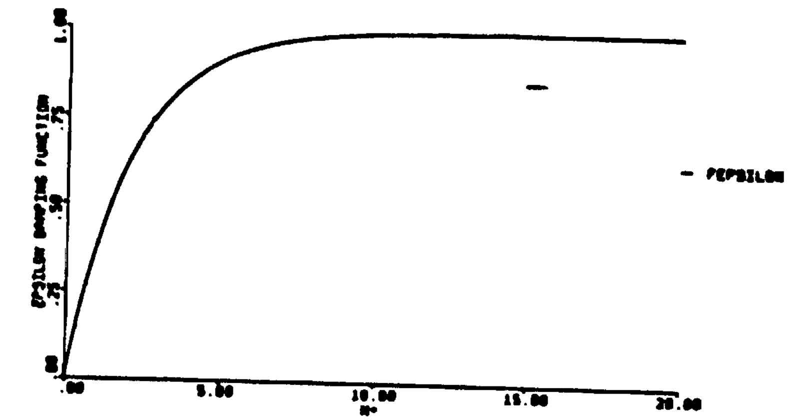


Figure 39: f_ϵ versus n^+

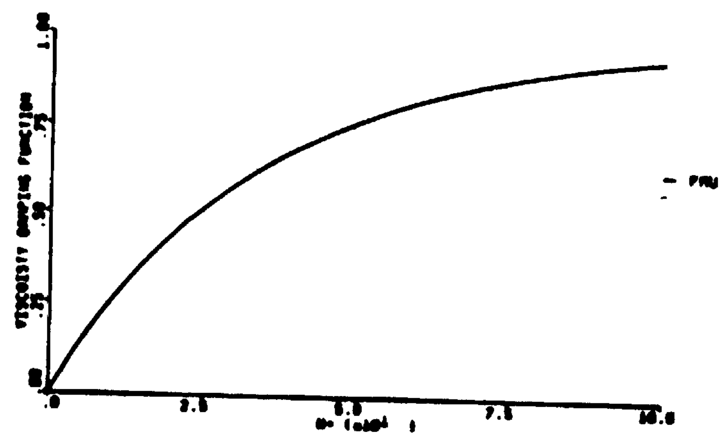


Figure 40: f_μ versus n^+

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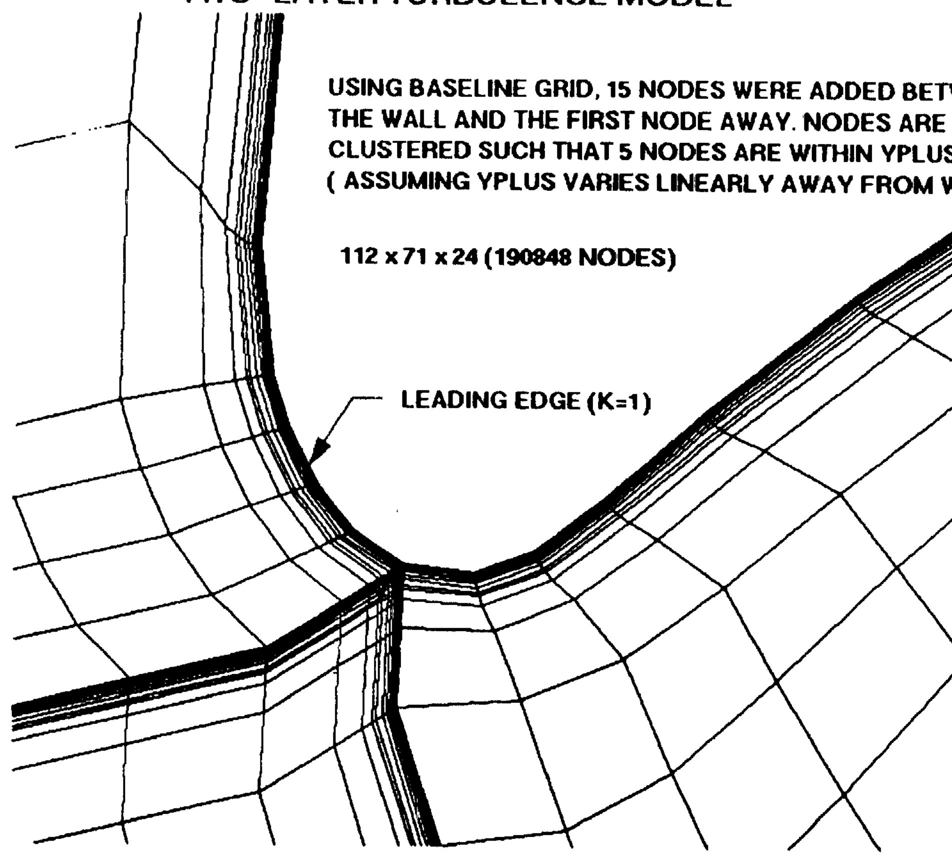
GGOT TOTAL PRESSURE LOSS/ GRID DEPENDENCY STUDY

TWO-LAYER TURBULENCE MODEL



GGOT TIP TREATMENT EVALUATION . STUDY

IN ORDER TO QUANTIFY THE BENEFITS OF POSSIBLE TIP TREATMENTS, THE BASELINE GRID WAS RUN AT ZERO GAP AND AT A MAXIMUM GAP OF 0.030 IN. THE NODE COUNT IN THE TIP GAP FOR THE MAX CLEARANCE CASE WAS INCREASED FROM 5 TO 11 FOR A GRID DIMENSION OF 82 x 41 x 30.

CASE	CLEARANCE [IN]	PLOSS	PLOSS/PLOSS NOM.
ZERO GAP	0.	0.1572	0.8912
NOM. GAP	0.015	0.1764	1.
MAX GAP	0.030	0.1810	1.0261

AS A RESULT OF THE GRID DEPENDENCY STUDY , THE AMOUNT OF VARIATION IN PRESSURE LOSS CALCULATED WAS +/- 4 % . IN ORDER TO ADEQUATELY ASSESS DIFFERENT TIP TREATMENTS, THE FOLLOWING PROCEDURES ARE SUGGESTED:

1.) SIMILAR GRIDS FOR ASSESSING TIP TREATMENTS SHOULD BE USED, WHEN POSSIBLE.
2.) TIP TREATMENT CASES SHOULD BE FIRST EVALUATED AT THE MAXIMUM GAP (0.030 IN) IN ORDER TO MAXIMIZE DIFFERENCES BETWEEN DIFFERENT TREATMENTS. GOOD TIP TREATMENT CANDIDATES WILL THEN BE ASSESSED AT THE NOMINAL CLEARANCE.

GIVEN THE RELATIVELY LARGE SURFACE AREA AT THE BLADE TIP, A PROMISING METHOD FOR REDUCING TIP LEAKAGE MAY BE TO CREATE A POCKETED SURFACE ON THE ROTOR TIP, SIMILAR TO A LABYRINTH SEAL.

IN ORDER TO DETERMINE THE SENSITIVE PARAMETERS INVOLVED, IT IS USEFUL TO EXAMINE A LABYRINTH SEAL FLOW EQUATION. THE FOLLOWING IS A METHOD PROPOSED BY VERMES (1961) WHICH IS A MODIFICATION OF MARTIN'S FORMULA FOR LABYRINTHS:

```
W=5.76 * K * A * PO * BETA/[R * TO * (1-ALPHA)]**.5

W=WEIGHT FLOW [LB/SEC]
K = f(RE, L/C)     -  CLEARANCE FACTOR OF SINGLE ANNULAR ORIFICE
A=ANNULAR ORIFICE FLOW AREA [IN**2]
PO=UPSTREAM TOTAL PRESSURE [PSI]
TO=UPSTREAM TOTAL TEMPERATURE [DEG R]
ALPHA=8.52/[(P-L)/C+7.23]   -  RESIDUAL ENERGY FACTOR
   P=DISTANCE BETWEEN TEETH [IN]
   L=TOOTH TIP WIDTH [IN]
   C=CLEARANCE [IN]
BETA={[1-(PN/PO)**2]/[N-LN(PN/PO)]}**.5    -    GLAND FACTOR
   PN=STATIC PRESSURE AT EXIT OF LAST TOOTH [PSI]
   N=NUMBER OF TEETH
R=GAS CONSTANT FT/DEG R
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GGOT TIP TREATMENT EVALUATION
STUDY

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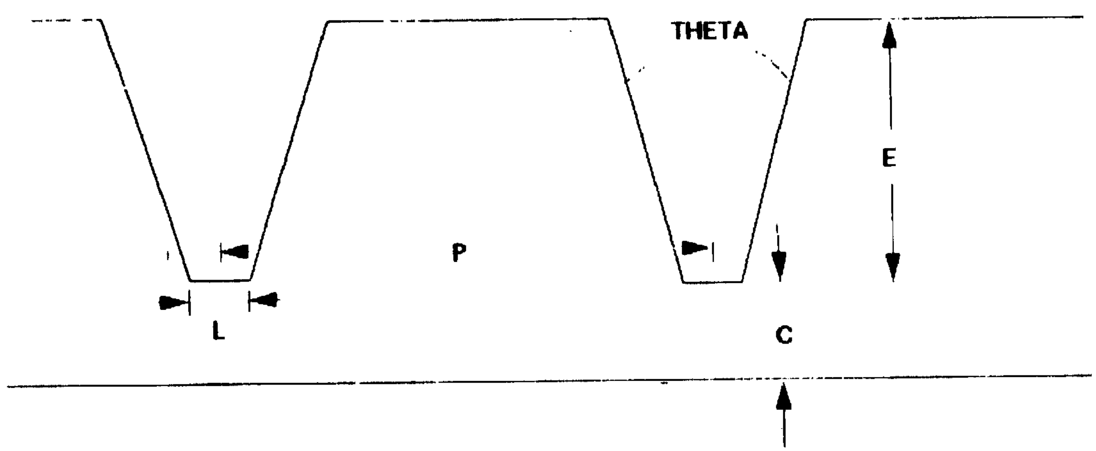

LABYRINTH GEOMETRY DEFINITION

GGOT TIP TREATMENT EVALUATION STUDY

ASSUMING PRESSURES, TEMPERATURES, SEAL CLEARANCE AND TOTAL SEAL LENGTH ARE DEFINED, THE REMAINING DESIGN PARAMETERS ARE NUMBER OF TEETH AND TOOTH WIDTH. ASSUMING MINIMUM TOOTH WIDTH (DETERMINED BASED ON STRUCTURAL REQUIREMENTS), THE ONLY REMAINING PARAMETER WHICH MAY BE MODIFIED IS THE NUMBER OF TEETH

THE VERMES FORMULA MAY BE HELPFUL IN TERMS OF A 1-D APPROACH IN DETERMINING THE APPROXIMATE NUMBER OF TEETH NECESSARY AND THEIR LOCATION IN ORDER TO MINIMIZE TIP LEAKAGE AS APPLIED TO THE GGOT. DUE TO THE COMPLICATED NATURE OF THE FLOW IN THE TIP GAP WITH THE COUNTER-ROTATING ENDWALL RETARDING THE FLOW THROUGH THE GAP, THE VERMES FORMULA WOULD PROBABLY NOT BE VERY USEFUL IN PREDICTING THE ACTUAL TIP LEAKAGE.

AS AN EXAMPLE APPLIED TO THE GGOT , A TYPICAL STREAMLINE STARTING NEAR THE LEADING EDGE IS SELECTED FROM THE MAX CLEARANCE CASE. THE ASSUMED PARAMETERS ARE:

L=.030 IN   C=.030 IN   PO=419.5 PSI   PN=197.8   TO=1261.2   LTOT=0.927 IN

NTEETH	PITCH	ALPHA	BETA	MDOT (NORM.)	
2	0.927	0.2295	0.5316	1.0	
3	0.463	0.3931	0.4553	0.9651	
4	0.309	0.5155	0.4046	0.9597	◄ OPTIMAL TOOTH NUMBER
5	0.232	0.6106	0.3677	0.9731	
6	0.185	0.6866	0.3394	1.0012	

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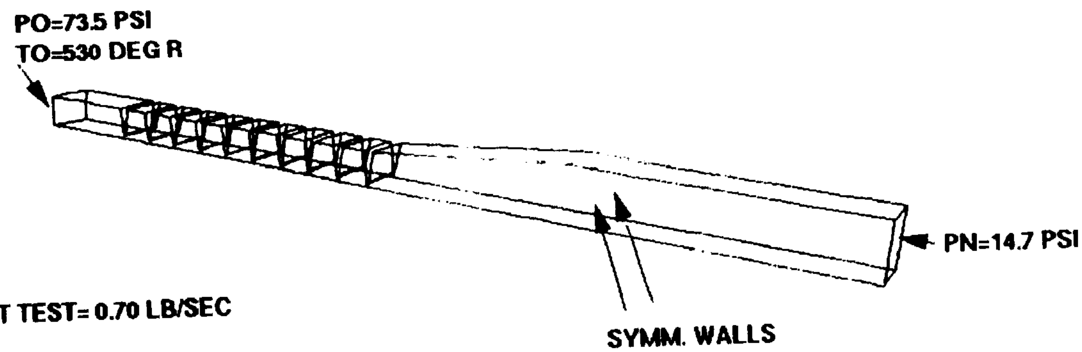
GGOT TIP TREATMENT EVALUATION STUDY

VALIDATION CASE FOR LABYRINTH SEAL BASED ON VERMES TEST DATA

FLUID: AIR

L=0.015 IN
E=0.25 IN
P=0.25 IN
C=0.030 IN
R=5 IN
THETA=14 DEG
NTEETH=10



MDOT TEST= 0.70 LB/SEC

MDOT CFD = 0.91 LB/SEC

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GGOT TIP TREATMENT EVALUATION STUDY

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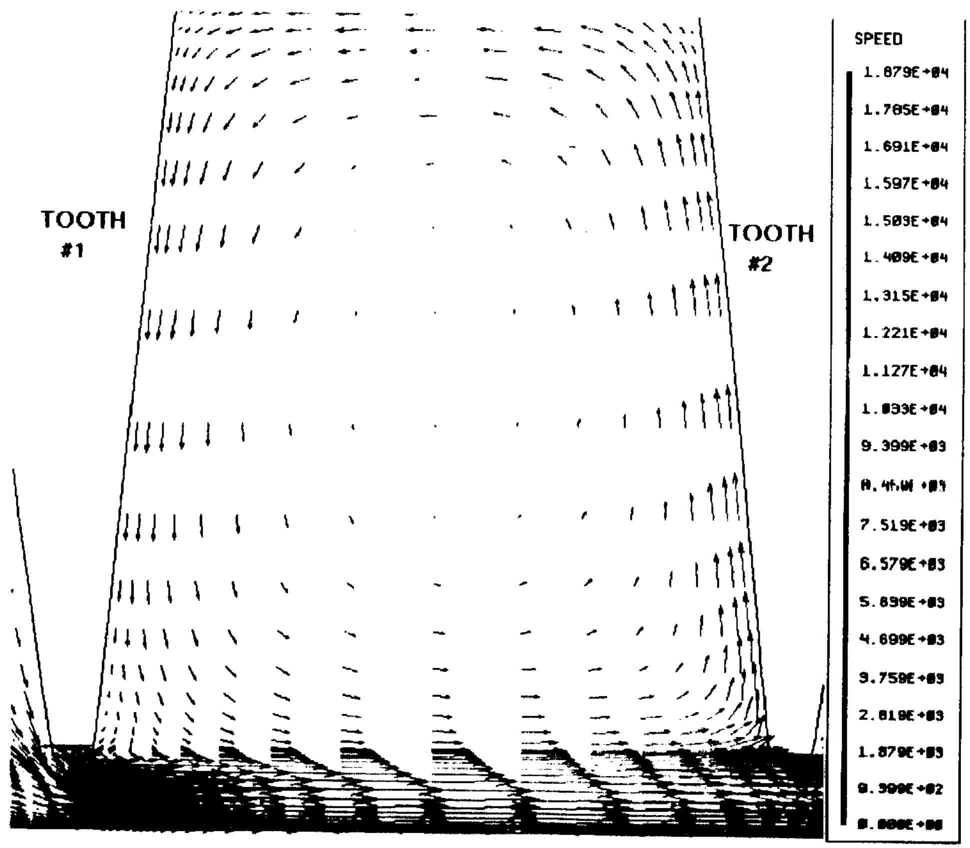
VALIDATION CASE FOR LABYRINTH SEAL BASED ON VERMES TEST DATA



GRID SIZE = 312 x 37 x 3

FIRST CAVITY

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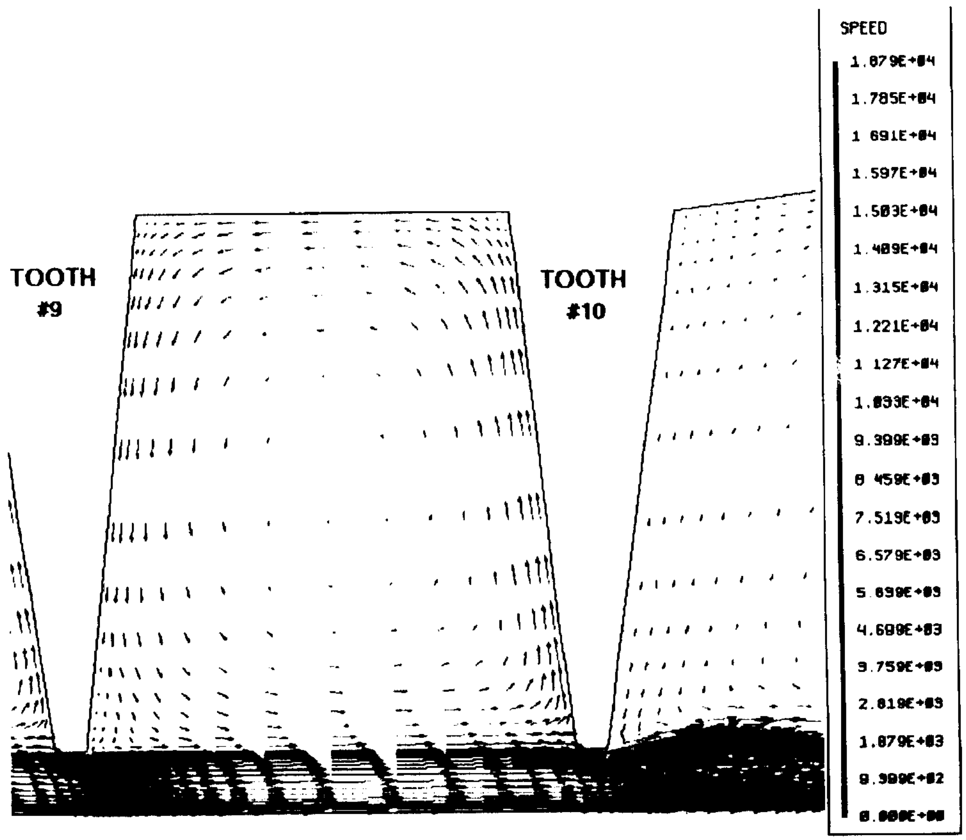
GGOT TIP TREATMENT EVALUATION STUDY

VALIDATION CASE FOR LABYRINTH SEAL BASED ON VERMES TEST DATA



GRID SIZE = 312 x 37 x 3

LAST CAVITY

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GGOT TIP TREATMENT EVALUATION STUDY

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CURRENT STATUS:

1.) RUNNING HOLLOW BLADE CASE (TWO-TOOTH LABYRINTH)

- 104 x 62 x 30 (10 NODES IN TIP GAP RADIAL DIRECTION)
- 0.030 IN WALL THICKNESS WITH 0.030 IN TIP CLEARANCE. HOLLOW PORTION OF BLADE EXTENDS FROM MIDSPAN TO TIP.
- RESULTS WILL BE COMPARED WITH SOLID BLADE TO ASSESS BENEFITS IN TERMS OF LOSS REDUCTION/ REDUCED LEAKAGE.

2.) CONSTRUCTING ROTOR GRID FOR BASELINE MULTI-TOOTH LABYRINTH TIP SEAL (USING GRID EMBEDDING)

- PARAMETERICS WILL BE NECESSARY TO OPTIMIZE DESIGN

3.) INVESTIGATING OTHER TIP TREATMENTS WHICH MAY REDUCE RELATIVE TOTAL PRESSURE LOSSES

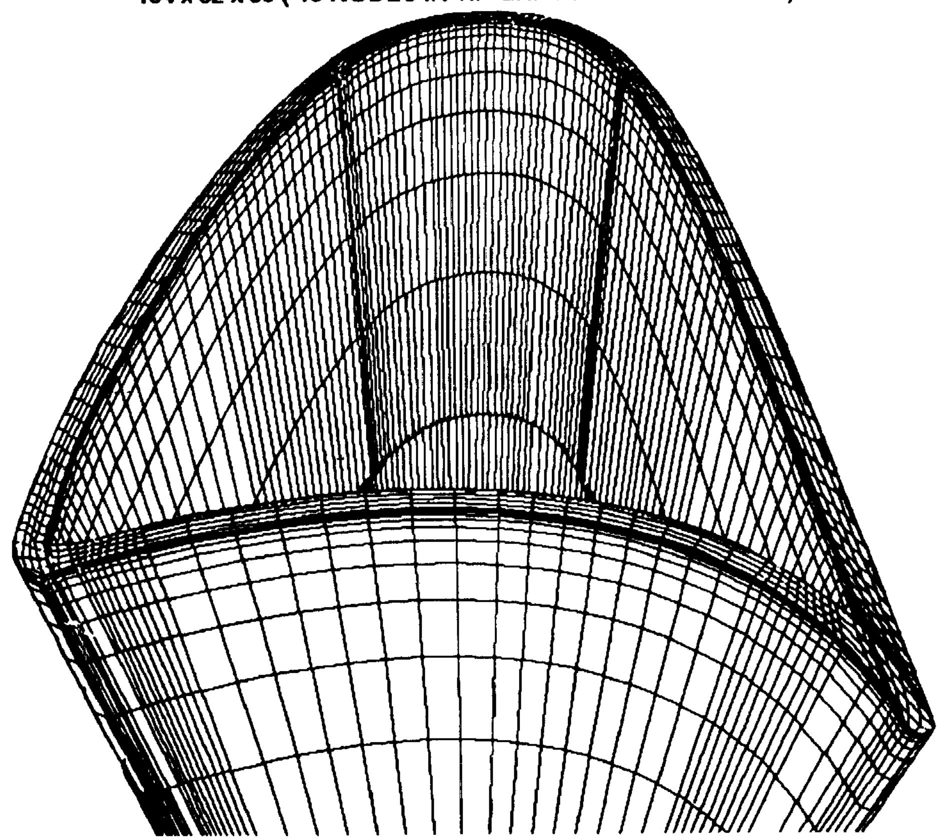
- SUCTION SIDE TRAILING EDGE SLOT TO PROVIDE FLOW GUIDANCE (TO REDUCE IMPINGEMENT ANGLE OF TIP LEAKAGE FLOW ON MAINSTREAM FLOW)

GenCorp Aerojet

GGOT TIP TREATMENT EVALUATION STUDY

Propulsion Division

PARTIALLY HOLLOW BLADE WITH 0.030 IN WALL THICKNESS
104 x 62 x 30 (10 NODES IN TIP GAP RADIAL DIRECTION)



GENCORP AEROJET

GGOT TIP TREATMENT EVALUATION STUDY

Propulsion Division

ALTERNATE TIP TREATMENT METHODS - TRAILING EDGE SUCTION-SIDE SLOT

OBJECTIVE: PROVIDE FLOW GUIDANCE TO REDUCE TIP LEAKAGE IMPINGEMENT ANGLE

ISSUES:
1.) NEED TO MAXIMIZE SLOT ANGLE TO PROVIDE MAXIMUM GUIDANCE.
2.) RESISTANCE PATH THOUGH SLOT SHOULD BE LESS THAN OVER TIP TO INDUCE FLOW THROUGH SLOT (FUNCTION OF FLOW AREA).
3.) SLOT DEPTH SHOULD BE MINIMIZED TO LOCALIZE EFFECTS TO TIP REGION.