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TRANDESNF: A Computer Program for Transonic Airfoil Design and Analysis in Nonuniform Flow

J. F. Chang and C. Edward Lan

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TRANDESNF: A Computer Program
for Transonic Airfoil Design
and Analysis in Nonuniform Flow

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INTRODUCTION

In this report, the usage of a transonic airfoil code for analysis, inverse design, and direct optimization of an airfoil immersed in propfan slipstream is described. For a detailed description of the theory, Reference 1 should be consulted.

In the following, a summary of the theoretical method, program capabilities, input format, output variables, and program execution are described. Input data of sample test cases and the corresponding output are given.
SUMMARY OF THE THEORETICAL METHOD

In the present method, the Euler equation is simplified by introducing a velocity function $\phi$ and a rotation function $F$. The latter is to account for the effect of flow nonuniformity, while the former is similar to the total velocity potential in the potential flow theory. The resulting equation can be shown to be (Ref. 1)

$$\left(a^2 - u^2\right)\phi_{xx} - 2uv\phi_{xy} + \left(a^2 - v^2\right)\phi_{yy} = uvF_y - \left(a^2 - u^2\right)F_x$$  (1)

where $a$ is the local speed of sound and $u, v$ are total velocity components in the $x$ and $y$ directions, respectively. Since the left-hand side of Equation (1) is the same as the full potential equation, it is convenient to modify an existing full-potential transonic airfoil code to solve the present problem. For this purpose, Carlson's code (Ref. 2) was chosen. The method of Reference 2 is based on a finite-difference approximation of Equation (1) in a Cartesian coordinate system. The finite-difference equations are solved by column relaxation. In the present problem, the rotation function and the stream function are also determined in the relaxation process.

To design an airfoil by direct optimization, the airfoil shape is expressed in a Fourier cosine series internally in the code with the Fourier coefficients being the design variables. Optimization of lift-to-drag ratio is accomplished by using CONMIN optimizer (Ref. 3) with lift and trailing-edge closure constraints.
PROGRAM CAPABILITIES

This program has the following features:

(1) It is applicable to the analysis, inverse design, and direct optimization of an airfoil in a transonic uniform or nonuniform flow. Boundary layer calculation may be included.

(2) The nonuniformity may be prescribed in the form of freestream Mach profile and/or temperature profile.

(3) The airfoil may be located vertically at any place in the nonuniform region.
INPUT DATA FORMAT

*** ALL INPUT DATA ARE IN THE LIST-DIRECTED FORMAT. ***

GROUP 1:  CASE DESCRIPTION

TITLE:  DESCRIPTION OF THE RUN CASE

GROUP 2:  READ INPUT OPTION

IOPT  EXECUTION OPTION:
   = 1 ANALYSIS OR INVERSE DESIGN
   = 2 PLOT LINEAR, NOT AVAILABLE IN THIS VERSION
   = 3 PLOT CONTOUR, NOT AVAILABLE IN THIS VERSION
   = 4 OPTIMIZE
   = 5 OPTIMIZE WITH PLOTS, NOT AVAILABLE IN THIS VERSION

IF IOPT = 1, SKIP GROUPS 3-15.

GROUPS 3-15 ARE CONMIN PARAMETERS (SEE REF. 3).

GROUP 3:

IPRINT = 0 PRINT NOTHING
   = 1 PRINT INITIAL AND FINAL INFORMATION
   = 2 FIRST DEBUG LEVEL
   = 3 SECOND DEBUG LEVEL
   = 4 COMPLETE DEBUG

ITMAX  MAXIMUM NUMBER OF ITERATIONS IN THE OPTIMIZATION PROCESS

NSCAL  SCALING CONTROL PARAMETER
   = -1 IF USER SUPPLIES SCALING VECTORS.
   = 0 IF THERE IS NO SCALING.
   = +1 FOR AUTOMATIC LINEAR SCALING EVERY NSCAL ITERATION.

GROUP 4:

NFDG  GRADIENT CALCULATION CONTROL PARAMETER
   = 0 IF ALL GRADIENT INFORMATION WILL BE CALCULATED BY
     FINITE DIFFERENCE.
   = 1 IF ALL GRADIENT INFORMATION IS PROVIDED BY SUBROUTINE
     ANALYSIS.
   = 2 IF GRADIENT OF OBJECTIVE FUNCTION IS PROVIDED BY
     ANALYSIS.
     USE 0 IN THIS VERSION.
GROUP 5:

FDCH = 0.01 TO 0.025 TYPICALLY FOR TRANSONIC AIRFOIL DESIGN.
RELATIVE CHANGE IN DECISION VARIABLE IN CALCULATING
FINITE DIFFERENCE GRADIENTS.

FDCHM = 0.00075 TO 0.0005 TYPICALLY FOR TRANSONIC AIRFOIL
DESIGN. MINIMUM ABSOLUTE STEP IN FINITE DIFFERENCE
GRADIENT CALCULATIONS. USE A SMALLER VALUE WHEN THE
AIRFOIL IS CLOSE TO THE OPTIMAL SHAPE.

GROUP 6:

ALPHAX = .1 TYPICALLY
ABOGJ1 = .1 TYPICALLY

GROUP 7:

NCON = NUMBER OF CONSTRAINT FUNCTIONS.
NSIDE = SIDE CONSTRAINT PARAMETER
 = 0 IF DESIGN VARIABLES DO NOT HAVE LOWER OR UPPER
  BOUNDS. THIS IS THE OPTION IN THIS VERSION.
 = 1 OTHERWISE.

GROUP 8:

LINOBJ = LINEAR OBJECTIVE FUNCTION IDENTIFIER.
 = 0 FOR NONLINEAR OBJECTIVE FUNCTION.
 = 1 FOR LINEAR OBJECTIVE FUNCTION.

GROUP 9:

CT = -.1 TYPICALLY. CONSTRAINT THICKNESS PARAMETER.
CTMIN = .004 TYPICALLY. MINIMUM ABSOLUTE VALUE OF CT
  CONSIDERED IN THE OPTIMIZATION PROCESS.
CTL = -.01 TYPICALLY. CONSTRAINT THICKNESS PARAMETER FOR
  LINEAR AND SIDE CONSTRAINTS.
CTLMIN = .001 TYPICALLY. MINIMUM ABSOLUTE VALUE OF CTL
  CONSIDERED IN THE OPTIMIZATION PROCESS.
THETA = 1. TYPICALLY. MEAN VALUE OF THE PUSH-OFF FACTOR IN
  THE METHOD OF FEASIBLE DIRECTIONS.
PHI = 5. TYPICALLY. PARTICIPATION COEFFICIENT, USED IF A
  DESIGN IS INFEASIBLE.

GROUP 10:

ITRM = 3 TYPICALLY. NUMBER OF CONSECUTIVE ITERATIONS TO
INDICATE CONVERGENCE BY RELATIVE OR ABSOLUTE CHANGES,
Delfun OR DABFUN.
GROUP 11:

DELFUN = .001 TYPICALLY.  MINIMUM RELATIVE CHANGE IN THE
OBJECTIVE FUNCTION TO INDICATE CONVERGENCE.
DABFUN = .001 TYPICALLY.  MINIMUM ABSOLUTE CHANGE IN THE
OBJECTIVE FUNCTION TO INDICATE CONVERGENCE.

GROUP 12:

N1 = NDV + 2, WHERE NDV = NCOEF*2
NCOEF  NUMBER OF TERMS IN THE FOURIER SERIES TO REPRESENT THE
AIRFOIL UPPER AND LOWER SURFACES.  >7 TYPICALLY.
IREP = 1 FOR READING DESIGN VARIABLES FROM PREVIOUS RUN FILE.
RECOMMENDED IN SUBSEQUENT ADDITIONAL RUNS.
= 0 OTHERWISE.

IF NSCAL ≠ -1, SKIP GROUP 13.

GROUP 13:

SCAL(N5)  VECTOR OF SCALING PARAMETERS, 40 VALUES.
          TYPICALLY, 40*0.001 FOR AIRFOIL DESIGN.

GROUP 14:

UPLIFT  UPPER LIFT CONSTRAINT
DNLIFT  LOWER LIFT CONSTRAINT
THTE  TRAILING-EDGE THICKNESS

GROUP 15:

X1  THE X-COORDINATE BEYOND WHICH THE AIRFOIL SHAPE IS TO
    BE OPTIMIZED.  NOTE THAT X(LE) = -0.5 AND X(TE) = 0.5.

*** THE FOLLOWING ARE MOSTLY TRANDES PARAMETERS.  SEE NASA CR-2821
     BY L. A. CARLSON.  ***

GROUP 16:  FREE STREAM CONDITIONS

M  MACH NUMBER
ALP  ANGLE OF ATTACK IN DEGREES
CIR  NONDIMENSIONAL CIRCULATION (HALF LIFT COEFFICIENT);
     USUALLY STARTS WITH 0.0
CDCORR  WAVE DRAG CORRECTION AT ZERO ANGLE OF ATTACK.
         CORRECTION SHOULD BE DETERMINED FOR EACH AIRFOIL
         AND GRID COMBINATION.
RN  REYNOLDS NUMBER
GROUP 17: COORDINATE STRETCHING PARAMETERS.
DO NOT CHANGE THE SUGGESTED VALUES OF THIS GROUP.

A1 STRETCHING CONSTANT FOR THE Y DIRECTION. SUGGESTED VALUE 0.246.
A2 X DIRECTION STRETCHING CONSTANT IN THE AIRFOIL REGION. SUGGESTED VALUE = 0.15.
A3 X DIRECTION STRETCHING CONSTANT OUTSIDE THE AIRFOIL REGION. SUGGESTED VALUE = 3.87.
A4 THE POSITIVE X LOCATION WHERE THE COORDINATE STRETCHING CHANGES. SUGGESTED VALUE = 0.49.
S4 CORRESPONDING X4 VALUE IN THE TRANSFORMED PLANE. SUGGESTED VALUE = 2.0.

GROUP 18: OPTION SPECIFIERS

IUNIFM FLOW TYPE INDICATOR
  = 0 FOR NONUNIFORM FLOW
  = 1 FOR UNIFORM FLOW

INV PROGRAM MODE PARAMETER
  = 0 FOR ANALYSIS OR DIRECT OPTIMIZATION
  = 1 FOR DESIGN

ITACT VISCOUS INTERACTION INDICATOR
  = 0 FOR INVISCID ANALYSIS AND DESIGN
  = 1 FOR ANALYSIS WITH INTERACTION

ITERP INTERPOLATION INDICATOR IN INVERSE DESIGN FOR INTERPOLATING INPUT CP DISTRIBUTION IN GRID 4
  = 0 CP TO BE READ IN GRID 4
  = 1 CP INTERPOLATED FROM GRID-3 INPUT

IDEBUG DEBUG INDICATOR
  = 0 NO DEBUGGING
  = 1 DEBUGGING
  = 2 CHECK PRESSURE DISTRIBUTION AT THE STABLE REGION FOR DESIGN

IREAD INDICATOR TO USE RESTART DATA
  = 0 IF RESTART DATA ARE NOT USED
  = 1 IF RESTART DATA ARE USED AND CONVERGED SOLUTION WILL BE Copied BACK TO DISK.
  = 2 IF RESTART DATA ARE READ FROM, BUT NOT WRITTEN ON, DISK 32. IN DIRECT OPTIMIZATION, DISK COPYING WILL BE Done AT THE END OF EXECUTION.

ITIME PROGRAM RESTART INDICATOR
  = 0 FOR NORMAL RUN
  = 1 FOR 10-MINUTE CPU LIMIT BUILT IN THE PROGRAM

IH Alf OPTION TO DETERMINE STARTING PHI VALUES FOR THE FINE GRIDS FROM VALUES CALCULATED IN THE COARSE GRIDS.
  = 0 AVERAGE VALUE
  = 1 ASYMMETRICAL QUADRATIC INTERPOLATION
  = 2 ASYMMETRICAL CUBIC INTERPOLATION
  = 3 SYMMETRICAL CUBIC INTERPOLATION

NOTE: IF IUNIFM = 1, SET ITERP = 0. TYPICALLY, IH Alf = 0.
GROUP 19: NUMBER OF SPECIFIERS

IMAX  NUMBER OF VERTICAL GRID LINES IN THE HORIZONTAL DIRECTION. LIMIT TO 97.
JMAX  NUMBER OF HORIZONTAL GRID LINES IN THE VERTICAL DIRECTION. LIMIT TO 97.
NHALSE NUMBER OF GRID REFINEMENTS. TYPICALLY, 2
MITER MAXIMUM NUMBER OF ITERATIONS. TYPICALLY, 1600-3200
LP RELAXATION CYCLE INTERVAL IN WHICH DETAILS OF BOUNDARY LAYER SURFACE COORDINATES, ETC., ARE PRINTED OUT. TYPICALLY, 4000-6000.

GROUP 20: VISCOUS INTERACTION PARAMETERS
INPUT TYPICAL VALUES FOR NO VISCOUS INTERACTION CASES

ITEUPC UPPER SURFACE TRAILING EDGE CORRECTION INDICATOR. ONLY USED IN THE VISCOUS INTERACTION CASE. = 0 FOR NO CORRECTION (TYPICAL)
1 WITH CORRECTION
ITELWC LOWER SURFACE TRAILING EDGE CORRECTION INDICATOR. SAME AS ITEUPC.
SP MAXIMUM VALUE ALLOWED FOR THE NASH-MACDONALD SEPARATION PARAMETER WHEN X < XSEP.
TYPICALLY, 0.004.
XSEP X LOCATION AFTER WHICH NASH-MACDONALD SEPARATION PARAMETER CAN ASSUME ITS CALCULATED VALUE.
TYPICALLY, 0.44.
XLSEP LOCATION AT WHICH THE TRAILING EDGE CORRECTION PROCEDURE BEGINS. IT SHOULD CORRESPOND TO THE POINT OF SEPARATION. TYPICALLY, 0.50. USED ONLY IF ITEUPC AND/OR ITELWC = 1.
XPC LOCATION AFTER WHICH LOWER SURFACE DISPLACEMENT THICKNESS IS REQUIRED TO CONTINUE DECREASING ONCE IT HAS STARTED TO DECREASE.
= 0.1 FOR AFT-CAMBERED AIRFOILS
0.5 FOR CONVENTIONAL AIRFOILS
XIBDLY THE X-LOCATION AT WHICH TRANSITION IS ASSUMED TO OCCUR. TYPICALLY, -.44.

GROUP 21: NONUNIFORM FLOW PARAMETERS

ISWIRL = 0 NO SWIRL
1 SWIRL EXISTS DUE TO PROPELLER
IANALY = 0 UNIFORM FLOW
1 MACH NUMBER PROFILE BY EXPONENTIAL EXPRESSIONS
2 MACH NUMBER PROFILE FROM INPUT FOR NONUNIFORM FLOW.
ISTAG = 0 UNIFORM STAGNATION TEMPERATURE PROFILE
1 UNIFORM AMBIENT TEMPERATURE PROFILE (TYPICAL)
2 INPUT STAGNATION TEMPERATURE PROFILE
3 EXPONENTIAL STAGNATION TEMPERATURE PROFILE
IBU = 0 LIFT COEFFICIENT BASED ON FREE-STREAM DYNAMIC PRESSURE
1 LIFT COEFFICIENT BASED ON MAXIMUM FAR FIELD DYNAMIC PRESSURE
2 LIFT COEFFICIENT BASED ON FAR FIELD DYNAMIC PRESSURE CORRESPONDING TO AIRFOIL STREAMLINE

GROUP 22: CONVERGENCE FACTORS

ICONV CONVERGENCE OPTION INDICATOR. A TYPICAL CHOICE IS 3.
= 0 CONSTANT CONV FOR EACH GRID
1 TWICE THE INPUT CONV FOR GRID ONE
2 FIVE TIMES THE INPUT CONV FOR GRID ONE
3 FIVE TIMES THE INPUT CONV FOR GRID ONE AND TWICE THE INPUT CONV FOR GRID TWO
4 SAME AS 3, BUT FIX AND RESET RELAXATION FACTOR AND SUPersonic Damping Factor AFTER 800 AND 1600 ITERATIONS.
5 SAME AS 4, BUT INCREASE ICYL TO 15 AFTER 2400 ITERATIONS

CONV CONVERGENCE CRITERION. IN DIRECT OPTIMIZATION, CONV IS INCREASED INTERNALLY BY 2.5 TIMES TO REDUCE CPU TIME IF CONV < 2.0 × 10^-6
= 1.0E-6 (TYPICAL) FOR NONUNIFORM FLOW
1.0E-4 (TYPICAL) FOR UNIFORM FLOW

RC REFERENCE CONVERGENCE FACTOR.
= 1000. TO 5000. TYPICAL FOR ANALYSIS
200. TYPICAL FOR DESIGN

FD RELATIVE CONVERGENCE FACTOR FOR NEWF.
= 10. TO 50. TYPICALLY. USE 1.0 FOR UNIFORM FLOW.

SD RELATIVE CONVERGENCE FACTOR FOR SHAPE
= 0.5 TYPICALLY. USE 1.0 FOR UNIFORM FLOW.

VD RELATIVE CONVERGENCE FACTOR FOR VISACT
= 2. TO 5. TYPICALLY

GROUP 23: RELAXATION FACTORS
INPUT DEFAULT VALUES FOR THOSE WHICH ARE NOT NEEDED

W RELAXATION FACTOR FOR PHI.
1.4 TO 1.7 TYPICAL

UW RELAXATION FACTOR FOR SHAPE.
0.4 < UW < 1.0

RDEL RELAXATION FACTOR FOR BOUNDARY LAYER DISPLACEMENT THICKNESS. USED ONLY FOR VISCOS INTERACTION FOR IMAX LE 55. TYPICALLY, 0.20. IT IS REDUCED AUTOMATICALLY BY HALF IN THE LAST FINE GrIDS. IT IS FURTHER REDUCED BY HALF IN DIRECT OPTIMIZATION.

RDELFN RELAXATION FACTOR FOR BOUNDARY LAYER DISPLACEMENT FOR IMAX. GT. 55. TYPICALLY, 0.125.
GROUP 24: DAMPING FACTORS

EPS SUBSONIC DAMPING FACTOR. TYPICALLY, 0.0.
EPSS STARTING SUPERSONIC DAMPING FACTOR.
EPSMIN MINIMUM SUPERSONIC DAMPING FACTOR. ROUGHLY EQUAL TO
SQRT (MAXIMUM LOCAL MACH NUMBER**2 -1.)

GROUP 25: AIRFOIL CALCULATION REGION

THIS GROUP SHOULD BE INPUT ONLY ONCE IN ANALYSIS MODE.
THIS GROUP SHOULD BE INPUT FOR EACH GRID IN DESIGN.

X1 X LOCATION WHERE DIRECT CALCULATION STOPS.
    = 0.5 IN ANALYSIS MODE OR IN DIRECT OPTIMIZATION.
    IN DESIGN MODE ALLOW AT LEAST TWO GRID POINTS AHEAD
    OF IT. -0.38 TYPICALLY.

X2 END OF INVERSE REGION.
    = 0.5 IN DESIGN MODE
    10000. IN ANALYSIS MODE OR DIRECT OPTIMIZATION.

IF IANALY ≠, SKIP GROUP 26. IN A UNIFORM FLOW, SKIP GROUPS 26-32.

GROUP 26: EXPONENTIAL VELOCITY PROFILE PARAMETERS.

QINF = QI * (1. + AC * EXP (1-((Y-YS)/DD)**2))

AC DIFFERENCE BETWEEN PEAK NONUNIFORM MACH NUMBER AND FREE-
STREAM MACH NUMBER.
YS VERTICAL LOCATION OF THE AIRFOIL RELATIVE TO THE
NONUNIFORM STREAM CENTER.
DD : VERTICAL SPREAD OF THE MACH NUMBER NONUNIFORMITY

IF IANALY ≠ 2, SKIP GROUPS 27 AND 28.

GROUP 27: NUMERICAL MACH NUMBER PROFILE PARAMETERS

ISTAl NUMBER OF STATIONS FOR SPECIFYING MACH NUMBER PROFILE
AC DIFFERENCE BETWEEN PEAK NONUNIFORM MACH NUMBER AND FREE
STREAM MACH NUMBER.

GROUP 28: NUMERICAL MACH NUMBER PROFILE.

YLOC Y LOCATIONS WHERE VELOCITIES ARE TO BE INPUT, ISTAl
VALUES. NONDIMENSIONALIZED WITH AIRFOIL CHORD LENGTH.
INPUT IN THE ORDER OF DECREASING VALUES.
VINF : CORRESPONDING MACH NUMBERS, ISTAl VALUES.

IF ISTAG ≠ 2, SKIP GROUPS 29 AND 30.
GROUP 29:
ISTA2   NUMBER OF STATIONS TO SPECIFY STAGNATION TEMPERATURE PROFILE.

GROUP 30:  STAGNATION TEMPERATURE PROFILE.
YLOC   Y LOCATIONS WHERE STAGNATION TEMPERATURES ARE TO BE INPUT, ISTA2 VALUES. NONDIMENSIONALIZED WITH AIRFOIL CHORD LENGTH. INPUT IN THE ORDER OF DECREASING VALUES.
TMP    : CORRESPONDING STAGNATION TEMPERATURE VALUES, ISTA2 VALUES.

IF ISTAG ≠ 3, SKIP GROUP 31.

GROUP 31:  EXPONENTIAL TEMPERATURE PROFILE PARAMETERS
TEM = (1 + TC * EXP(-((Y - TS)/TD)**2))
TC    DIFFERENCE BETWEEN PEAK TEMPERATURE AND FREE STREAM TEMPERATURE
TS    VERTICAL LOCATION OF THE AIRFOIL RELATIVE TO THE NONUNIFORM TEMPERATURE PROFILE CENTER
TD    VERTICAL SPREAD OF THE TEMPERATURE NONUNIFORMITY

IF ISWIRL ≠ 1, SKIP GROUP 32.

GROUP 32:  SWIRL PARAMETERS
SWANG   SWIRL ANGLE IN DEGREES
SWBL    Y COORDINATE BELOW WHICH FREE STREAM CONDITIONS PREVAIL
SWBU    Y COORDINATE ABOVE WHICH FREE STREAM CONDITIONS PREVAIL

GROUP 33:
NI    NUMBER OF COORDINATE PAIRS TO DESCRIBE THE UPPER SURFACE OF THE AIRFOIL. LIMITED TO 110.

GROUP 34:
(XI, YI)   AIRFOIL UPPER SURFACE COORDINATES (X, Y) NONDIMENSIONALIZED WITH CHORD LENGTH. NI PAIRS. INPUT FROM THE LEADING EDGE TO THE TRAILING EDGE. X(LE) = 0. AND X(TE) = 1.0.
GROUP 35: UPPER SURFACE SLOPES

DERIX  DX/DS OF THE AIRFOIL UPPER SURFACE AT THE LEADING EDGE. TYPICALLY, 0.0.

DERIY  DY/DS OF THE AIRFOIL UPPER SURFACE AT THE TRAILING EDGE. TYPICALLY, 1.0.

DERFX  THIRD DERIVATIVE OF DX/DS OF THE AIRFOIL UPPER SURFACE AT THE TRAILING EDGE. TYPICALLY, 0.0.

DERFY  THIRD DERIVATIVE OF DY/DS OF THE AIRFOIL UPPER SURFACE AT THE TRAILING EDGE. TYPICALLY, 0.0.

GROUP 36:

NIB  NUMBER OF COORDINATE PAIRS TO DESCRIBE THE AIRFOIL LOWER SURFACE. LIMITED TO 110.

GROUP 37:

(XIB,YIB)  AIRFOIL LOWER SURFACE COORDINATES (x, y). NONDIMENSIONALIZED WITH CHORD LENGTH. NIB PAIRS. INPUT FROM THE LEADING EDGE TO THE TRAILING EDGE. X(LE) = 0. AND X(TE) = 1.0.

GROUP 38: LOWER SURFACE SLOPES.

DERIXB  DX/DS OF THE AIRFOIL LOWER SURFACE AT THE LEADING EDGE. TYPICALLY, 0.0.

DERIYB  DY/DS OF THE AIRFOIL LOWER SURFACE AT THE LEADING EDGE. TYPICALLY, -1.0.

DERFXB  THIRD DERIVATIVE OF DX/DS OF THE AIRFOIL LOWER SURFACE AT THE TRAILING EDGE. TYPICALLY, 0.0.

DERFYB  THIRD DERIVATIVE OF DY/DS OF THE AIRFOIL LOWER SURFACE AT THE TRAILING EDGE. TYPICALLY, 0.0.

SKIP GROUPS 39-40 IF
1. ANALYSIS CASES OR DIRECT OPTIMIZATION
2. MHALF = 1
3. ITERP = 1 AND GRID FINER THAN GRID 3
   THIS GROUP SHOULD BE INPUT FOR GRID 2 AND 3.
   IF ITERP = 0, IT SHOULD ALSO BE INPUT FOR GRID 4.

GROUP 39:

CPU  SPECIFIED Cp DISTRIBUTION ON THE UPPER SURFACE AT GRID POINTS. INPUT FROM THE LEADING EDGE TO THE TRAILING EDGE. SEE NASA CR-2821.
GROUP 40:

CPL SPECIFIED $C_p$ DISTRIBUTION ON THE LOWER SURFACE AT GRIP POINTS. INPUT FROM THE LEADING EDGE TO THE TRAILING EDGE. SEE NASA CR-2821.
OUTPUT VARIABLES

The following output is available on file #30 for each grid.

(1) The input profiles for the free-stream Mach number and temperature are first printed.

(2) Heading

(3) Listing of input data

(4) Cartesian grid coordinates. Pairs of I,X(I) are first printed. These are followed with pairs of J,Y(J).

(5) Airfoil coordinates

X  HORIZONTAL COORDINATE WITH -0.5 BEING THE LEADING EDGE AND 0.5 BEING THE TRAILING EDGE
YU  UPPER SURFACE ORDI NATE
YL  LOWER SURFACE ORDI NATE
UPPER SLOPE  UPPER SURFACE SLOPE
LOWER SLOPE  LOWER SURFACE SLOPE

(6) Iteration history

ITER  ITERATION NUMBER
CIR  CIRCULATION
DPM  MAXIMUM $\phi$ CORRECTION AT THE GRID LOCATION (I,J)
NSSP  NUMBER OF SUPersonic POINTS
DELT A  MAXIMUM BOUNDARY LAYER DISPLACEMENT THICKNESS
EPSS  SUPersonic DAMPING FACTOR
W  RELAXATION FACTOR FOR $\phi$
UW  RELAXATION FACTOR FOR AIRFOIL SHAPE IN INVERSE DESIGN

(7) Results of boundary layer analysis (for cases with viscous interaction only)

X  HORIZONTAL COORDINATE
YUORIG  ORIGINAL UPPER SURFACE ORDI NATE
DU  UPPER SURFACE DISPLACEMENT THICKNESS
SLU  SLOPE OF UPPER SURFACE ORDI NATE
YLORIG  ORIGINAL LOWER SURFACE ORDI NATE
DL  LOWER SURFACE DISPLACEMENT THICKNESS
SLL  SLOPE OF LOWER SURFACE
(8) Pressure distribution on airfoil

<table>
<thead>
<tr>
<th>X</th>
<th>HORIZONTAL COORDINATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>PRESSURE COEFFICIENT Cₚ ON THE UPPER SURFACE</td>
</tr>
<tr>
<td>CPL</td>
<td>PRESSURE COEFFICIENT ON THE LOWER SURFACE</td>
</tr>
</tbody>
</table>

(9) Airfoil shape with boundary layer displacement thickness included

<table>
<thead>
<tr>
<th>X</th>
<th>HORIZONTAL COORDINATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>YU</td>
<td>UPPER SURFACE ORDINATE</td>
</tr>
<tr>
<td>YL</td>
<td>LOWER SURFACE ORDINATE</td>
</tr>
<tr>
<td>SLU</td>
<td>SLOPE OF UPPER SURFACE</td>
</tr>
<tr>
<td>SLL</td>
<td>SLOPE OF LOWER SURFACE</td>
</tr>
</tbody>
</table>

(10) Mach number chart

"I" increases from top to bottom and "J" increases from left to right. The actual value of Mach number is the printed value divided by 100.

(11) Wave drag coefficient and wave drag correction (CDCORR)

(12) Plot of results

<table>
<thead>
<tr>
<th>U</th>
<th>UPPER SURFACE Cₜ</th>
</tr>
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<tbody>
<tr>
<td>L</td>
<td>LOWER SURFACE Cₜ</td>
</tr>
<tr>
<td>T</td>
<td>UPPER DISPLACEMENT SURFACE</td>
</tr>
<tr>
<td>B</td>
<td>LOWER DISPLACEMENT SURFACE</td>
</tr>
<tr>
<td>CPSTAR</td>
<td>CRITICAL PRESSURE COEFFICIENT, C*</td>
</tr>
<tr>
<td>CLCIR</td>
<td>LIFT COEFFICIENT FROM CIRCULATION</td>
</tr>
<tr>
<td>CL</td>
<td>LIFT COEFFICIENT FROM C INTEGRATION</td>
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<tr>
<td>CD</td>
<td>TOTAL DRAG COEFFICIENT</td>
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<td>CMLE</td>
<td>PITCHING MOMENT COEFFICIENT ABOUT THE LEADING EDGE</td>
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<tr>
<td>CDF</td>
<td>SKIN FRICTION DRAG COEFFICIENT</td>
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<tr>
<td>CMG4</td>
<td>PITCHING MOMENT COEFFICIENT ABOUT THE QUARTER-CHORD POINT</td>
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(13) CPU time

In direct optimization, various CONMIN variables may be printed, depending on printing options. For details, Reference 3 should be consulted.
PROGRAM EXECUTION

This code is written in Fortran 77 language. It is operational on the Harris-1000 computer at the University of Kansas and the CDC Cyber 175 computer system at the NASA Langley Research center.

The following files used during execution are defined in the program:

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<th>FILE VARIABLE</th>
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<td>20</td>
<td>INPUT DATA</td>
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<td></td>
<td>22</td>
<td>TO STORE DESIGN VARIABLES FOR RESTART IN DIRECT OPTIMIZATION</td>
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<tr>
<td>JOUT</td>
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<td>OUTPUT</td>
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<tr>
<td>IOUT</td>
<td>31</td>
<td>DATA IN INPUT-DATA FORMAT CONTAINING THE FINAL AIRFOIL COORDINATES IN DIRECT OPTIMIZATION FOR RESTART</td>
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File numbers may be redefined in BLOCK DATA. The file #22 is used in Subroutines OPT and COEI.

Execution in analysis and inverse design is straightforward.

In direct optimization, the following steps are recommended.

(1) With an assumed starting airfoil, run the code in analysis mode with IREAD = 0 (see GROUP 18). The converged solution is automatically saved on file LOUT (#32).

(2) Change the input file for direct optimization. The following values for some input variables are recommended:

ITMAX = 2 (GROUP 3)
IREP = 0 (GROUP 12)
IREAD = 1 (GROUP 18)
CONV = 2.5x10^{-6} (GROUP 12)
RDEL = 0.1 (GROUP 23)
EPSS = 3.0 (GROUP 24)

(3) The final solution is again saved on file LOUT (#32). If the output indicates that the objective function is not changed, FDCHM (GROUP 5) may be slightly increased. To restart, copy file IOUT (#31) to file INPUT (#20), and IREP (GROUP 12) is set to 1. ITMAX (GROUP 3) may be increased. Other variables in step (2) remain the same.

(4) For any subsequent restart, step (3) is repeated.

(5) After a satisfactory airfoil shape is obtained, file IOUT (#31) is copied to file INPUT (#20) again. The file INPUT (#20) is then changed for analysis only. For this final analysis, the following values for some input variables are recommended:

IREAD = 1 (GROUP 18)
CONV = 1.0x10^{-6} (GROUP 23)
RDEL = 0.2 (GROUP 23)
EPSS = 2.5 (GROUP 24)
## SAMPLE INPUT AND OUTPUT

1. **Input Data for Sample Case 1**

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**Pressure Coefficient**

- \( C_{PSTAR} = -0.1965 \)
- \( C^{LCLT}_{p} = 0.7130 \)
- \( C^{DF}_{p} = 0.000000 \)
- \( C^{MC4}_{p} = -0.3569 \)

**Final EPSS**

- 2.800000

**Freestream Mach Number Profile**

- 0.9185
- 0.9140
- 0.9104
- 0.9078
- 0.8851
- 0.8555
- 0.8060
- 0.8000
- 0.2500
- 0.6000
- 0.9230

**Freestream Stagnation Temperature Profile**

- 1.1280
- 1.1280
- 1.1280
- 1.1472
- 1.1659
- 1.1687
- 1.1704
- 1.1728
- 1.1742
- 1.1741
- 1.1729
- 1.1716
- 1.1704
NASA AIRFOIL IN NON-UNIFORM FLOW (NASA ORIGINAL)

1. INVISIDAL ANALYSIS CASE

WITH VISCOSITY INTERACTION

0.8390 0.8150 0.8530 0.8390 0.8390
0.8400 0.8150 0.8530 0.8390 0.8390
25.9 25.9 60.9 0.0000 0.0000
1.0000 1.0000 1.0000 1.0000
0.0000 5.0000 1.4000

X-Y GRID SYSTEM

1. -0.0027E+01 2. -0.3872E+01 3. -0.1410E+01 4. -0.6471E+00 5. -0.4900E+00 6. -0.4307E+00 7. -0.3706E+00
8. -0.3028E+00 9. -0.1485E+00 10. -0.1686E+00 11. -0.1247E+00 12. -0.6240E-01 13. 0.0000E+00 14. 0.6240E-01
15. 0.1247E+00 16. 0.1686E+00 17. 0.1247E+00 18. 0.6240E-01 19. 0.3706E+00 20. 0.4307E+00 21. 0.4900E+00

AERIAL CORRDINATES

X 0.0000 0.0196 0.0392 0.0588 0.0784 0.0980
Y 0.0000 0.0413 0.0826 0.1239 0.1652 0.2065

BEGINNING EPS = 10.0000000000
BEGINNING DEG = 0.0000000000

ITER = 10 CLR = 3.1036 DPM = 0.00503616 AT 7 11 NESP = 223 DELTA = 0.0000 EPS = 5.0000 W = 1.40 UW = 1.00

ITER = 20 CLR = 3.3087 DPM = 0.00345023 AT 8 11 NESP = 171 DELTA = 0.0000 EPS = 5.0000 W = 1.40 UW = 1.00

ITER = 50 CLR = 3.5142 DPM = 0.00153299 AT 8 11 NESP = 140 DELTA = 0.0015 EPS = 5.0000 W = 1.50 UW = 1.00
a.

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**Pressure Coefficient**

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**Note:** The table contains numerical data that is not clearly readable due to the image quality.
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Nasa Airfoil in Non-uniform Flow (Nasa Original)
\begin{align*}
\text{FINAL EPPSS} &= 1.410e+02 \\
\text{CPU TIME AFTER ANALYSIS} &= 1.52 - 0.05 \text{ SECONDS}
\end{align*}
3. Input Data for Sample Case 2

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<td>0.7 0.06173 0.71 0.06173 0.72 0.06173 0.73 0.06173</td>
</tr>
<tr>
<td>0.74 0.06173 0.75 0.06173 0.76 0.06173 0.77 0.06173</td>
</tr>
<tr>
<td>0.78 0.06173 0.79 0.06173 0.8 0.06173 0.81 0.06173</td>
</tr>
<tr>
<td>0.82 0.06173 0.83 0.06173 0.84 0.06173 0.85 0.06173</td>
</tr>
<tr>
<td>0.86 0.06173 0.87 0.06173 0.88 0.06173 0.89 0.06173</td>
</tr>
<tr>
<td>0.89 0.06173 0.9 0.06173 0.91 0.06173 0.92 0.06173</td>
</tr>
<tr>
<td>0.93 0.06173 0.94 0.06173 0.95 0.06173 0.96 0.06173</td>
</tr>
<tr>
<td>0.97 0.06173 0.98 0.06173 0.99 0.06173 1.0 0.06173</td>
</tr>
<tr>
<td>0.4000</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>0.2300</td>
</tr>
<tr>
<td>0.2900</td>
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<tr>
<td>0.3100</td>
</tr>
<tr>
<td>0.3500</td>
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<tr>
<td>0.3900</td>
</tr>
<tr>
<td>0.4100</td>
</tr>
<tr>
<td>0.4200</td>
</tr>
<tr>
<td>0.4900</td>
</tr>
</tbody>
</table>

| -1.218 | -1.016 | -0.514 | -0.512 | -0.410 | -0.208 | -0.006 | 0.196 | 0.396 | 0.800 | 0.802 |

**PRESsURE COEFFICIENT**

**COSTAS = 0.2078**
**CLCL = 0.557**
**CD = 0.064439**
**CMLE = 0.5295**
**CDF = 0.007767**
**CMC4 = -0.3346**

**FINAL EPSS = 1.603000**

**CPU TIME AFTER ANALYSIS = 30.537 SECONDS**

**N11 = 6**
**NIIF = 9**

**WRK = 95**

**-0.0365**

**-0.0420**

**-0.0265**

**-0.0304**

**-0.0344**

**-0.0238**

**-0.0191**

**-0.0235**

**-0.0185**

**-0.0132**

**-0.0038**

**-0.03437**

**ITERATION TRACE = 1**

---

**CONMIN**

**FORTRAN PROGRAM FOR**

**CONSTRAINED FUNCTION MINIMIZATION**

---

**DESIGN OF AN AIRFOIL IN NON-UNIFORM TRANSONIC FLOW**

**MACH NO. IS 0.800 ANGLE OF ATTACK IS 0.000 DEGREES**

**DIRECT SOLUTION TO 0.50**

**INVISID ANALYSIS CASE**

**WITH VISCUS INTERACTION**

**0.036000 0.000000 0.25756 0.000000 0.000000 0.000000 0.000000 0.000000**

**0.046000 0.015000 0.187000 0.000000 0.40000 0.40000 0.000000 0.000000**

**49 49 0.054000 0.440000 0.01000 0.440000**

**1 1 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000**

**1.40000 1.00000 0.05000 0.00000 1.00000 0.00000 0.00000 0.00000**

**0.03000 1.70000 1.40000**
DESIGN OF AN AIRFOIL IN NON-UNIFORM TRANSONIC FLOW

\[ \text{WAVE COEF } = 0.056732 \quad \text{CD} = 0.000000 \]

\[ \begin{array}{cccccc}
0 & -1.32 & -1.01 & 0.81 & 0.27 & -0.20 & -0.006 & 0.19 & 0.39 & 0.59 & 0.80
\end{array} \]

\[ \begin{array}{cccccc}
-0.34 & 0.01 & 0.37 & 0.40 & 0.37 & 0.14 & 0.04 & 0.1 & 0.31 & 0.32 & 0.21
\end{array} \]

\[ \begin{array}{cccccc}
-0.34 & 0.01 & 0.37 & 0.40 & 0.37 & 0.14 & 0.04 & 0.1 & 0.31 & 0.32 & 0.21
\end{array} \]

\[ \begin{array}{cccccc}
-0.34 & 0.01 & 0.37 & 0.40 & 0.37 & 0.14 & 0.04 & 0.1 & 0.31 & 0.32 & 0.21
\end{array} \]
CONstrained FUNCTION MINIMIZATION

CONTROL PARAMETERS

PRINT  NOV  ITMAX  NCON  NSIDE  ICONDIR  NSCAL  NDFG
0      14     2      3      15      -1       3

ST       CT       EFSTN       DEFU        G1TMN
-0.10000E+00  0.40000E-02    -0.10000E-01  0.10000E-02

THETA      PHI       DEFLN        DAFLN
D.10000E+01  0.50000E-01    0.10000E-02   0.10000E-02

EDCH      EDFUM        ALMAX       ASDJ
D.10000E-01  0.60000E-03     0.10000E+00  0.10000E+00

SCALING VECTOR (SCAL)
0.10000E-02  0.10000E-02  0.10000E-32  0.10000E-02  0.10000E-02  0.10000E-02

ALL CONSTRAINTS ARE NON-LINEAR

INITIAL FUNCTION INFORMATION

OBJ = -0.120247E+02

DECISION VARIABLES (X-VECTOR)

{ 1 } -0.364759E-01  -0.238383E-01  -0.490317E-01  -0.499437E-01  -0.131229E-03  -0.772577E-03  -0.178883E-03

CONSTRAINT VALUES (G-VECTOR)

{ 1 } -0.927509E-01  -0.354808E-01  -0.173855E-02

BEGIN ITERATION NUMBER 1

ST = -0.10000E+03  CTI = -0.10000E-01  PHI = 0.50000E+01
BEGINNING EPS = 1.50000 BEGINNING DEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 7
BEGIN NEW
AT ITERATION = 10
BEGIN VISACY
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 145 CIR = 10

3.26569 DPM = 0.0000223 AT 548 NSSP = 567 DELTA = 0.0119 EPSS = 1.60 W = 1.70 UW = 1.00
WAVE CD = 0.056504 CDORR = 0.000000
PRESSURE COEFFICIENT

0
CPS8R = -0.2077 CLEIR = 0.5338

FINAL EPSS = 1.600000

1
BEGINNING EPSS = 1.600000 BEGINNING RDEL = 0.050000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEW
AT ITERATION = 10
BEGIN VISACY
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 147 CIR = 10

0.26524 DPM = 0.0000325 AT 372 NSSP = 568 DELTA = 0.0119 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.057315 CDORR = 0.000000
PRESSURE COEFFICIENT

0
CPS8R = -0.2077 CLEIR = 0.5338

FINAL EPSS = 1.400000

1
BEGINNING EPSS = 1.400000 BEGINNING RDEL = 0.050000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEW
AT ITERATION = 10
BEGIN VISACY
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 169 CIR = 10

0.26730 DPM = 0.000025 AT 4146 NSSP = 568 DELTA = 0.0116 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.055523 CDORR = 0.000000
PRESSURE COEFFICIENT

0
CPS8R = -0.2077 CLEIR = 0.5346

FINAL EPSS = 1.400000

1
BEGINNING EPSS = 1.400000 BEGINNING RDEL = 0.050000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEW
AT ITERATION = 10
BEGIN VISACY
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 159 CIR = 10

0.26730 DPM = 0.000025 AT 4146 NSSP = 568 DELTA = 0.0116 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.055523 CDORR = 0.000000
PRESSURE COEFFICIENT

0
CPS8R = -0.2077 CLEIR = 0.5346

FINAL EPSS = 1.400000

1
BEGINNING EPSS = 1.400000 BEGINNING RDEL = 0.050000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEW
AT ITERATION = 10
BEGIN VISACY
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 149 CIR = 10

0.26730 DPM = 0.000025 AT 4146 NSSP = 568 DELTA = 0.0116 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.055523 CDORR = 0.000000
PRESSURE COEFFICIENT
FINAL EPSS = 1.400030
1
BEGINNING EPSS = 1.400000 BEGINNING RDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1 BEGIN NEW
BEGIN VISAC
AT ITERATION = 10 END
STABLE REGION
AT ITERATION = 10
ITER = 245 CIR = 3.26708 DP = 0.00000223 AT 43.24 NISP = 569 DELTA = 0.0105 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.056735 CDR = 0.000000 PRESSURE COEFFICIENT

FINAL EPSS = 1.400030
1
BEGINNING EPSS = 1.400000 BEGINNING RDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1 BEGIN NEW
BEGIN VISAC
AT ITERATION = 10 END
STABLE REGION
AT ITERATION = 10
ITER = 457 CIR = 0.27351 DP = 0.00000225 AT 31.22 NISP = 570 DELTA = 0.0124 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.056735 CDR = 0.000000 PRESSURE COEFFICIENT

FINAL EPSS = 1.400030
1
BEGINNING EPSS = 1.400000 BEGINNING RDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1 BEGIN NEW
BEGIN VISAC
AT ITERATION = 10 END
STABLE REGION
AT ITERATION = 10
ITER = 579 CIR = 0.26352 DP = 0.00000225 AT 27.21 NISP = 573 DELTA = 0.0103 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.057245 CDR = 0.000000 PRESSURE COEFFICIENT

FINAL EPSS = 1.400030
1
BEGINNING EPSS = 1.400000 BEGINNING RDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1 BEGIN NEW
BEGIN VISAC
AT ITERATION = 10 END
STABLE REGION
AT ITERATION = 10
BEGIN VISACT
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 255 CIR = 0.26558
DPm = 0.0000025 AT 22.21 NSSP = 572 DELTA = 0.0117 EPSS = 1.42 W = 1.70 UW = 1.00
WAVE CD = 0.056923 CEFDRR = 0.000000
PRESSURE COEFFICIENT
CPSTAR = 0.2074 CLCIR = 0.5322
FINAL EPSS = 1.420030
BEGINNING EPSS = 1.42003 BEGINNING RDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEW
AT ITERATION = 10
BEGIN VISACT
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 255 CIR = 0.26558
DPm = 0.0000025 AT 22.21 NSSP = 572 DELTA = 0.0117 EPSS = 1.42 W = 1.70 UW = 1.00
WAVE CD = 0.056923 CEFDRR = 0.000000
PRESSURE COEFFICIENT
CPSTAR = 0.2074 CLCIR = 0.5322
FINAL EPSS = 1.420030
BEGINNING EPSS = 1.42003 BEGINNING RDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEW
AT ITERATION = 10
BEGIN VISACT
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 600 CIR = 0.26538
DPm = 0.0000025 AT 28.21 NSSP = 576 DELTA = 0.0118 EPSS = 1.41 W = 1.70 UW = 1.00
WAVE CD = 0.056873 CEFDRR = 0.000000
PRESSURE COEFFICIENT
CPSTAR = 0.2070 CLCIR = 0.5268
FINAL EPSS = 1.410030
BEGINNING EPSS = 1.41003 BEGINNING RDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEW
AT ITERATION = 10
BEGIN VISACT
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10
ITER = 748 CIR = 0.27024
DPm = 0.0000025 AT 24.21 NSSP = 572 DELTA = 0.0120 EPSS = 1.40 W = 1.70 UW = 1.00
WAVE CD = 0.057925 CEFDRR = 0.000000
PRESSURE COEFFICIENT
CPSTAR = 0.2084 CLCIR = 0.5405
\( \text{FINAL EPSS} = 1.400030 \)

1. **BEGINNING EPSS:** 1.400030  
   **BEGINNING ROEL:** 0.05000  
   **ACCEPTABLE REGION FOR ANALYSIS**  
   **AT ITERATION:** 1  
   **BEGIN NEW:**  
   **AT ITERATION:** 10  
   **BEGIN VISACY:**  
   **AT ITERATION:** 10  
   **STABLE REGION:**  
   **AT ITERATION:** 10  
   **ITER:** 817  
   **CIR:** 0.26122  
   **DPM:** 0.0000025  
   **AT:** 37.46  
   **NISP:** 570  
   **DELTA:** 0.0117  
   **EPSS:** 1.41  
   **W:** 1.70  
   **UW:** 1.00  
   **WAVE CD:** 0.056716  
   **CORN CD:** 0.000000  
   **PRESSURE COEFFICIENT**  

\( \text{FINAL EPSS} = 1.410030 \)

1. **BEGINNING EPSS:** 1.410030  
   **BEGINNING ROEL:** 0.05000  
   **ACCEPTABLE REGION FOR ANALYSIS**  
   **AT ITERATION:** 1  
   **BEGIN NEW:**  
   **AT ITERATION:** 10  
   **BEGIN VISACY:**  
   **AT ITERATION:** 10  
   **STABLE REGION:**  
   **AT ITERATION:** 10  
   **ITER:** 944  
   **CIR:** 0.27273  
   **DPM:** 0.0000025  
   **AT:** 21.21  
   **NISP:** 570  
   **DELTA:** 0.0121  
   **EPSS:** 1.40  
   **W:** 1.70  
   **UW:** 1.00  
   **WAVE CD:** 0.056861  
   **CORN CD:** 0.000000  
   **PRESSURE COEFFICIENT**  

\( \text{FINAL EPSS} = 1.400030 \)

1. **BEGINNING EPSS:** 1.400030  
   **BEGINNING ROEL:** 0.05000  
   **ACCEPTABLE REGION FOR ANALYSIS**  
   **AT ITERATION:** 1  
   **BEGIN NEW:**  
   **AT ITERATION:** 10  
   **BEGIN VISACY:**  
   **AT ITERATION:** 10  
   **STABLE REGION:**  
   **AT ITERATION:** 10  
   **ITER:** 940  
   **CIR:** 0.26207  
   **DPM:** 0.0000024  
   **AT:** 43.24  
   **NISP:** 572  
   **DELTA:** 0.0117  
   **EPSS:** 1.41  
   **W:** 1.70  
   **UW:** 1.00  
   **WAVE CD:** 0.057980  
   **CORN CD:** 0.000000  
   **PRESSURE COEFFICIENT**  

\( \text{FINAL EPSS} = 1.410030 \)

1. **BEGINNING EPSS:** 1.410030  
   **BEGINNING ROEL:** 0.05000  
   **ACCEPTABLE REGION FOR ANALYSIS**  
   **AT ITERATION:** 1  
   **BEGIN NEW:**  
   **AT ITERATION:** 10  
   **BEGIN VISACY:**  
   **AT ITERATION:** 10  
   **STABLE REGION:**  
   **AT ITERATION:** 10  
   **ITER:** 940  
   **CIR:** 0.26207  
   **DPM:** 0.0000024  
   **AT:** 43.24  
   **NISP:** 572  
   **DELTA:** 0.0117  
   **EPSS:** 1.41  
   **W:** 1.70  
   **UW:** 1.00  
   **WAVE CD:** 0.057980  
   **CORN CD:** 0.000000  
   **PRESSURE COEFFICIENT**  

**THERE ARE 3 ACTIVE CONSTRAINTS**  
**CONSTRAINT NUMBERS ARE 3 2 3**  
**THERE ARE 0 VIOLATED CONSTRAINTS**
BEGIN ITERATION NUMBER 2

1) GRADIENT OF OBJ
   \[ \begin{bmatrix}
   0.344256e-01 & 0.526263e-01 & -0.322841e+00 & -0.343475e+00 & -0.199686e+00 & 0.784937e+00
   \end{bmatrix} \]

2) GRADIENTS OF ACTIVE AND VIOLATED CONSTRAINTS
   \[ \begin{bmatrix}
   0.339786e-01 & 0.570356e-01 & -0.262077e+00 & -0.100739e+00 & 0.192293e+00 & -0.183318e+00
   \end{bmatrix} \]

3) CONSTRAINT NUMBER 1
   \[ \begin{bmatrix}
   0.340321e-01 & -0.511535e+00 & -0.160027e+00 & -0.113769e+00 & 0.335916e+00 & 0.192803e+00
   \end{bmatrix} \]

4) CONSTRAINT NUMBER 2
   \[ \begin{bmatrix}
   0.336462e-01 & 0.200330e-01 & -0.450442e-01 & -0.371929e-01 & -0.378758e+00 & 0.329884e+00
   \end{bmatrix} \]

5) CONSTRAINT VALUES (X-VECTOR)
   \[ \begin{bmatrix}
   0.035346e-01 & -0.200330e-01 & 0.100017e+00 & -0.135616e+01 & 0.190672e+00 & 0.329884e+00
   \end{bmatrix} \]

6) CONSTRAINT NUMBER 3
   \[ \begin{bmatrix}
   -0.566350e+00 & 0.259408e+00 & -0.173555e+00
   \end{bmatrix} \]

BEGIN ITERATION NUMBER 2

CT = 0.34200e-01
CTL = 0.46416e-02
PHI = 0.50000e+01

THERE ARE 3 ACTIVE CONSTRAINTS
THERE ARE 3 VIOLATED CONSTRAINTS
CONSTRAINT PARAMETER, BETA = 0.1406E+01

SEARCH DIRECTION (S-VECTOR)
{[1]} -0.3455E-01 -0.3475E-01 -0.3427E-01 -0.3487E-01 -0.3464E-01 -0.3427E-01 -0.3487E-01 -0.3464E-01 -0.3427E-01

ONE-DIMENSIONAL SEARCH
INITIAL SLOPE = -0.1632E+01 PROPOSED ALPHA = -0.3920E-02

* * * CONSTRAINED ONE-DIMENSIONAL SEARCH INFORMATION * * *

PROPOSED DESIGN
ALPHA = 0.8493E-02
S-VECTOR
0.3345E-01 0.2200E-01 -0.2255E-01 -0.4525E-01 -0.2255E-01 -0.1375E-01 -0.3739E-01 -0.1873E-01 -0.3547E-01
BEGINNING EPS= 1.47000 BEGINNING PDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEWF
AT ITERATION = 10
BEGIN VISACT
AT ITERATION = 10
STABLE REGION
AT ITERATION = 10

ITER = 74 FP CIP = 3.26647 SEP = 0.200025 AT 43.24 NSEP = 572 DELTA = 0.0119 EPSS = 1.42 W = 1.70 UW = 1.00
WAVE CD = 0.056763 CDSEP = 0.000000 PRESSURE COEFFICIENT
\( \text{CSTAR} = -0.3036 \text{ CLEIR} = 0.5328 \)
\( \text{CL} = 0.7754 \text{ CD} = 0.364526 \text{ CM} = -0.5273 \text{ COF} = 0.007766 \text{ CMCA} = -0.3335 \)

FINAL EPSS = 1.420000

1 ITERATION TRACE = 17

03J = -0.12017E+02

CONSTRAINT VALUES
-0.1219E+00 -0.5544E-02 -0.6951E-02

TWO-POINT INTERPOLATION

PROPOSED DESIGN
ALPHA = 0.29639E-02
S-VECTOR
0.3345E-01 0.2200E-01 -0.2255E-01 -0.4525E-01 -0.2255E-01 -0.1375E-01 -0.3739E-01 -0.1873E-01 -0.3547E-01
BEGINNING EPS= 1.47000 BEGINNING PDEL = 0.05000
ACCEPTABLE REGION FOR ANALYSIS
AT ITERATION = 1
BEGIN NEWF
AT ITERATION = 10
BEGIN VISACT
<table>
<thead>
<tr>
<th>AT ITERATION</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>STABLE REGION</td>
<td></td>
</tr>
<tr>
<td>AT ITERATION</td>
<td>10</td>
</tr>
<tr>
<td>ITR = 55 CTR = 3.26248 \frac{\text{dp}}{m} = 0.000000 \text{At 39.13 m} \text{wsp} = 572 \text{Delta} = 0.0119 \text{EPSS} = 1.52 \text{w} = 1.55 \text{uw} = 1.00</td>
<td></td>
</tr>
<tr>
<td>WAVE CD = 0.056776</td>
<td>CLE = -0.5327</td>
</tr>
<tr>
<td>PRESSURE COEFFICIENT</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FINAL EPSS = 1.52003</td>
<td></td>
</tr>
<tr>
<td>ITERATION TRACE = 18</td>
<td></td>
</tr>
<tr>
<td>O3J = -0.12011E+02</td>
<td></td>
</tr>
<tr>
<td>CONSTRAINT VALUES</td>
<td></td>
</tr>
<tr>
<td>-0.4735E+01</td>
<td>-0.3470E-02</td>
</tr>
<tr>
<td>THREE-POINT INTERPOLATION</td>
<td></td>
</tr>
<tr>
<td>PROPOSED DESIGN</td>
<td></td>
</tr>
<tr>
<td>ALPH = 0.29933E-03</td>
<td></td>
</tr>
<tr>
<td>X-VECTOR</td>
<td></td>
</tr>
<tr>
<td>0.3463E+01</td>
<td>0.2000E-01</td>
</tr>
<tr>
<td>0.2580E-01</td>
<td>0.1500E+02</td>
</tr>
<tr>
<td>BEGINNING EPSS = 1.32003</td>
<td>BEGINNING REL = 0.00000</td>
</tr>
<tr>
<td>ACCEPTABLE REGION FOR ANALYSIS</td>
<td></td>
</tr>
<tr>
<td>AT ITERATION = 10</td>
<td></td>
</tr>
<tr>
<td>ITR = 10 CTR = 3.36455</td>
<td>\frac{\text{dp}}{m} = 0.000003 \text{At 49.76 m} \text{wsp} = 572 \text{Delta} = 0.0119 \text{EPSS} = 1.52 \text{w} = 1.40 \text{uw} = 1.00</td>
</tr>
<tr>
<td>WAVE CD = 0.056776</td>
<td>CLE = -0.5327</td>
</tr>
<tr>
<td>PRESSURE COEFFICIENT</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FINAL EPSS = 1.52003</td>
<td></td>
</tr>
<tr>
<td>ITERATION TRACE = 19</td>
<td></td>
</tr>
<tr>
<td>O3J = -0.12011E+02</td>
<td></td>
</tr>
<tr>
<td>CONSTRAINT VALUES</td>
<td></td>
</tr>
<tr>
<td>-0.4754E+01</td>
<td>-0.4945E-02</td>
</tr>
<tr>
<td>*** END OF ONE-DIMENSIONAL SEARCH</td>
<td></td>
</tr>
<tr>
<td>CALCULATED ALPH = -0.26645E-13</td>
<td></td>
</tr>
<tr>
<td>O3J = -0.120247E+02</td>
<td>NO CHANGE ON O3J</td>
</tr>
<tr>
<td>DECISION VARIABLES (X-VECTOR)</td>
<td></td>
</tr>
<tr>
<td>{ 1 } 0.396465E-01</td>
<td>0.264300E-01</td>
</tr>
<tr>
<td>{ 6 } -0.347555E-01</td>
<td>-0.294855E-01</td>
</tr>
<tr>
<td>CONSTRAINT VALUES (6-VECTOR)</td>
<td></td>
</tr>
<tr>
<td>{ 1 } -0.923593E-01</td>
<td>-0.364530E-01</td>
</tr>
</tbody>
</table>
FINAL OPTIMIZATION INFORMATION

\[ C_{ij} = -0.120247E+02 \]

DECISION VARIABLES (X-VECTOR)
\[
\begin{align*}
\{1\} & : -0.306668E-01 -0.333036E+01 -0.200447E-01 -0.123920E-02 -0.319222E-01 -0.379122E-01 -0.175822E-02 -0.176122E-02 -0.300000E-08 \\
\{2\} & : -0.306668E-01 -0.333036E+01 -0.200447E-01 -0.123920E-02 -0.319222E-01 -0.379122E-01 -0.175822E-02 -0.176122E-02 -0.300000E-08 \\
\{3\} & : -0.306668E-01 -0.333036E+01 -0.200447E-01 -0.123920E-02 -0.319222E-01 -0.379122E-01 -0.175822E-02 -0.176122E-02 -0.300000E-08 \\
\{4\} & : -0.306668E-01 -0.333036E+01 -0.200447E-01 -0.123920E-02 -0.319222E-01 -0.379122E-01 -0.175822E-02 -0.176122E-02 -0.300000E-08 \\
\end{align*}
\]

CONSTRAINT VALUES (C-VECTOR)
\[
\begin{align*}
\{1\} & : -0.923598E-01 -0.333036E+01 -0.176122E-02 \\
\{2\} & : -0.923598E-01 -0.333036E+01 -0.176122E-02 \\
\{3\} & : -0.923598E-01 -0.333036E+01 -0.176122E-02 \\
\{4\} & : -0.923598E-01 -0.333036E+01 -0.176122E-02 \\
\end{align*}
\]

THERE ARE 1 ACTIVE CONSTRAINTS
CONiRAIY NUMBERS ARE

THERE ARE 0 VIOLATED CONSTRAINTS

TERMINATION CRITERION
INFCNT EQUALS ITMAX

NUMBER OF ITERATIONS = 2

OBJECTIVE FUNCTION WAS EVALUATED 18 TIMES
CONTRAINT FUNCTIONS WERE EVALUATED 13 TIMES

THE FINAL AIRFOIL SHAPE

\[
\begin{array}{cccc}
X/C & Y/U/C & X/C & Y/L/C \\
0.300000 & 0.000300 & 0.300000 & 0.000300 \\
0.400000 & 0.000600 & 0.400000 & 0.000600 \\
0.500000 & 0.000900 & 0.500000 & 0.000900 \\
0.600000 & 0.001200 & 0.600000 & 0.001200 \\
0.700000 & 0.001500 & 0.700000 & 0.001500 \\
0.800000 & 0.001800 & 0.800000 & 0.001800 \\
0.900000 & 0.002100 & 0.900000 & 0.002100 \\
1.000000 & 0.002400 & 1.000000 & 0.002400 \\
1.100000 & 0.002700 & 1.100000 & 0.002700 \\
1.200000 & 0.003000 & 1.200000 & 0.003000 \\
1.300000 & 0.003300 & 1.300000 & 0.003300 \\
1.400000 & 0.003600 & 1.400000 & 0.003600 \\
1.500000 & 0.003900 & 1.500000 & 0.003900 \\
1.600000 & 0.004200 & 1.600000 & 0.004200 \\
1.700000 & 0.004500 & 1.700000 & 0.004500 \\
1.800000 & 0.004800 & 1.800000 & 0.004800 \\
1.900000 & 0.005100 & 1.900000 & 0.005100 \\
2.000000 & 0.005400 & 2.000000 & 0.005400 \\
2.100000 & 0.005700 & 2.100000 & 0.005700 \\
2.200000 & 0.006000 & 2.200000 & 0.006000 \\
2.300000 & 0.006300 & 2.300000 & 0.006300 \\
2.400000 & 0.006600 & 2.400000 & 0.006600 \\
2.500000 & 0.006900 & 2.500000 & 0.006900 \\
2.600000 & 0.007200 & 2.600000 & 0.007200 \\
2.700000 & 0.007500 & 2.700000 & 0.007500 \\
2.800000 & 0.007800 & 2.800000 & 0.007800 \\
2.900000 & 0.008100 & 2.900000 & 0.008100 \\
3.000000 & 0.008400 & 3.000000 & 0.008400 \\
\end{array}
\]
<table>
<thead>
<tr>
<th>X</th>
<th>YV02S</th>
<th>DU</th>
<th>SLU</th>
<th>YV02S</th>
<th>DL</th>
<th>SSL</th>
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</table>

The table contains data points for X, YV02S, DU, SLU, YV02S, and DL, with corresponding values for SSL. The values range from 0.0 to 2.0 in increments of 0.1.
<table>
<thead>
<tr>
<th>Coefficient</th>
<th>T8</th>
<th>T9</th>
<th>U</th>
<th>U</th>
<th>L</th>
<th>L</th>
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</thead>
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<tr>
<td>0</td>
<td>-1.216</td>
<td>-1.015</td>
<td>-0.813</td>
<td>-0.612</td>
<td>-0.411</td>
<td>-0.209</td>
</tr>
</tbody>
</table>

Final EPSS = 1.520050

CPU time after analysis = 5818.956 seconds
REFERENCES


Abstract

In this report, the usage of a transonic airfoil code for analysis, inverse design, and direct optimization of an airfoil immersed in propfan slipstream is described. For a detailed description of the theory, Reference 1 should be consulted.

In the following, a summary of the theoretical method, program capabilities, input format, output variables, and program execution are described. Input data of sample test cases and the corresponding output are given.

Key Words (Suggested by Authors(s))
- Propfan
- Wing Design
- Pressure Distributions
- Transonic Flow
- Nacelle Design

Distribution Statement
Unclassified - Unlimited