# AUTOMATED DESIGN OF CONTROLLED DIFFUSION BLADES

Jose M. Sanz

NASA Lewis Research Center

## ABSTRACT

A numerical automation procedure has been developed to be used in conjuction with an inverse hodograph method for the design of controlled diffusion blades.
With this procedure a cascade of airfoils with a prescribed solidity, inlet Mach No., inlet air flow angle and air flow turning can be produced automatically.
The trailing edge thickness of the airfoil, an important quantity in inverse methods, is also prescribed.

The automation procedure consists of a multi-dimensional Newton iteration in which the objective design conditions are achieved by acting on the hodograph input parameters of the underlying inverse code.

The method, although more general in scope, is applied in this paper to the design of axial flow turbomachinery blade sections, both compressors and turbines. A collaborative effort with U.S. Engine Companies to identify designs of interest to the industry will be described.

# CURRENT APPROACH

- GUESS GEOMETRY
  - SINGLE CIRCULAR ARC
  - MULTIPLE CIRCULAR ARC
  - POLYNOMIAL SHAPES
  - NACA AIRFOILS SERIES

- ANALYZE SHAPE WITH FLOW SOLVER
  - 2-D, QUASI 3-D OR 3-D CODES
  - POTENTIAL, EULER OR NAVIER-STOKES SOLVERS

- BUILDS IN EMPIRICISM

# AUTOMATION PROCEDURE

- ITERATION OF INVERSE HODOGRAPH METHOD

- PRODUCES BLADE WITH PRESCRIBED
  - SOLIDITY
  - INLET MACH NUMBER
  - INLET AIR ANGLE
  - AIR FLOW TURNING
  - TRAILING EDGE THICKNESS

# BENEFITS

- REPLACE TRIAL AND ERROR PROCESS BY EXACT 2-D SOLUTION
- GREATLY REDUCES MANPOWER AND TURN AROUND TIME
- INITIALLY OPTIMIZED BLADE SECTIONS
- INNOVATIVE DESIGNS
- MAJOR IMPACT FOR DESIGNS PROBLEMS WITH NO DATA BASE

- TO IMPLEMENT AUTOMATION

  EQUATION $u = \mathscr{F}\,(R, M_0, \theta, q\,(s))$

  IS REPLACED BY

$$\bar{y} = \bar{F}\,(\bar{x})$$

WHERE

$$\bar{x} = (R, M_0, \theta, Q_M, Q_{te}, S_{te})$$

$$\bar{y} = \bar{y}\,(\sigma, M_1, \beta_1, \Delta\beta, dn_{te}, ds_{te})$$

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NEWTON ITERATION TO SOLVE VECTOR EQUATION

$$\bar{F}(x) - \bar{y}_o = 0,$$

$$\bar{y}_o = (\sigma, \ M_1, \beta_1, \Delta\beta, dn_{te}, ds_{te})_o$$

IS OBJECTIVE FUNCTION.

ITERATION

$$\bar{X}_{n+1} = \bar{X}_n - J^{-1} (\bar{x}_n) (\bar{y}_n - \bar{y}_o)$$

JACOBIAN: $J = \left( \frac{\partial F_i}{\partial x_j} \right)$

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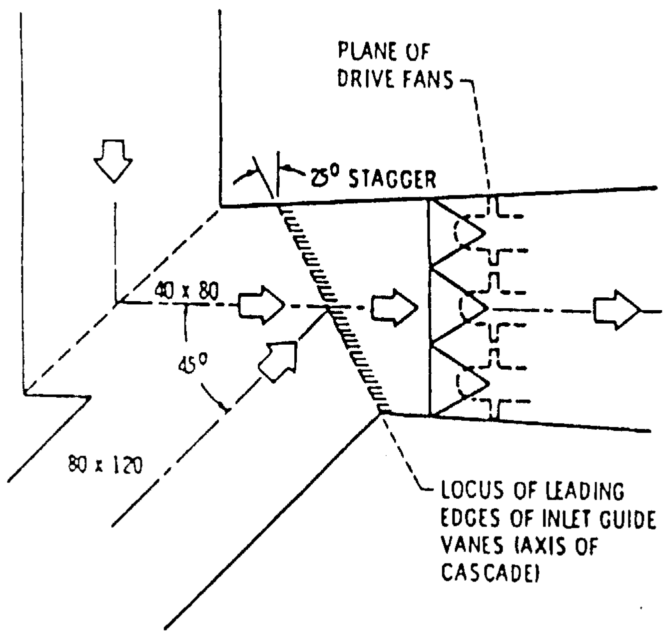
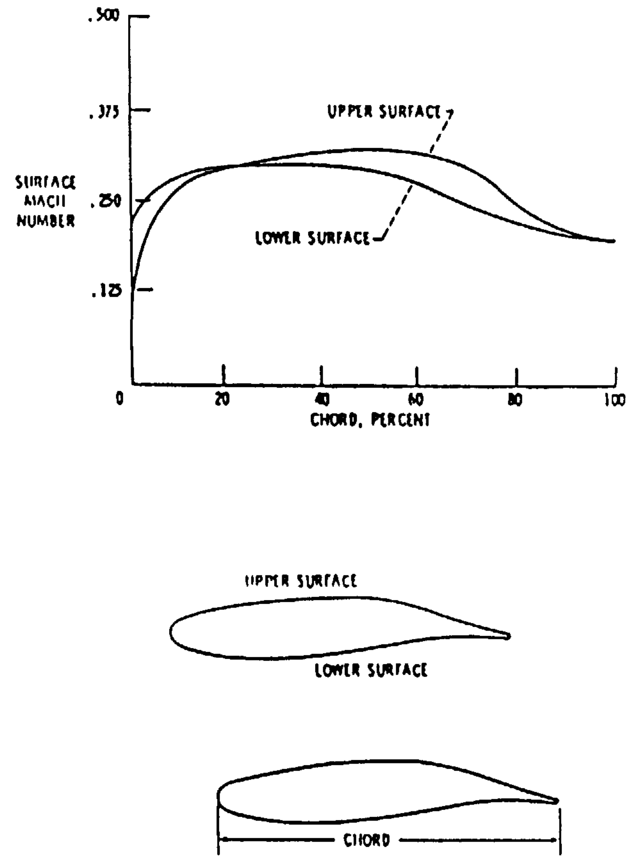
# APPLICATIONS

- ARC 40X80X120 WIND TUNNEL TURNING VANES
- SUBSONIC AND TRANSONIC (SHOCK-FREE) TURBOMACHINERY AND PROPELLER SECTIONS
- INLET GUIDE VANES FOR LARGE RANGE OF INLET AIR FLOW ANGLE - EXPERIMENTAL VERIFICATION 3/88

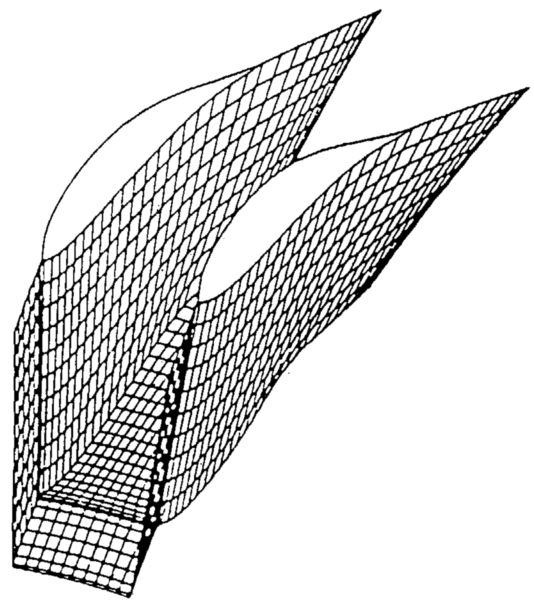
# ARC 40X80X120 WIND TUNNEL TURNING VANES

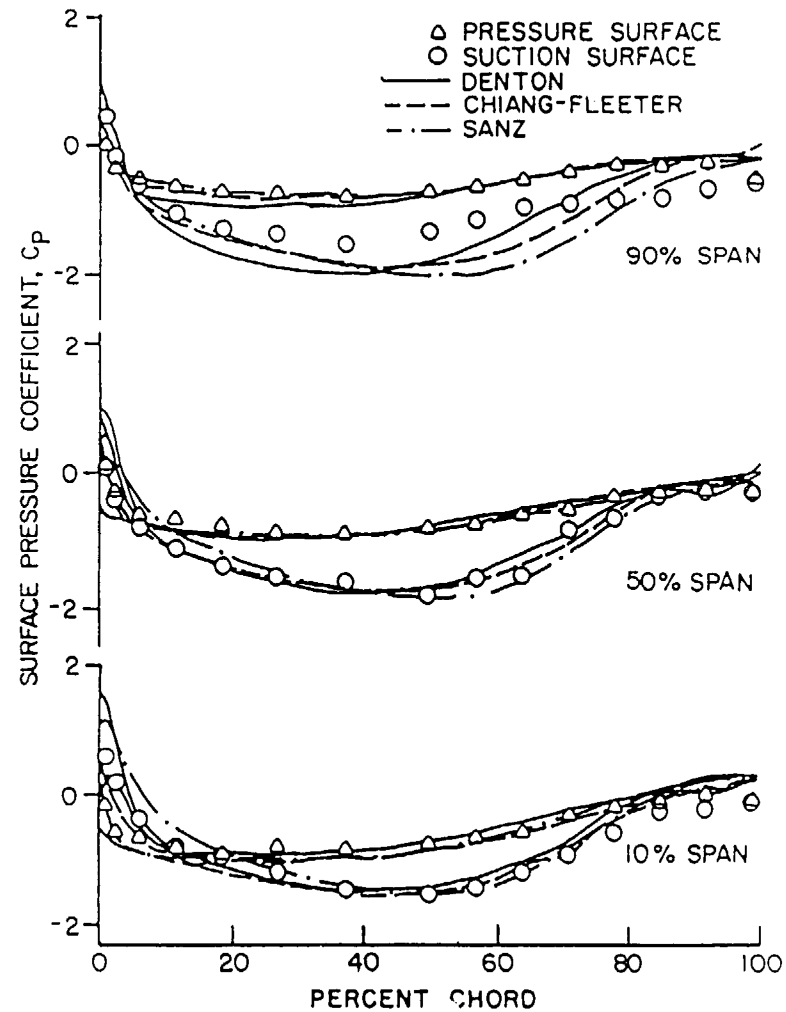
SCHEMATIC OF THE JUNCTION OF THE NASA AMES
40 x 80/80 x 120 FOOT WIND TUNNEL



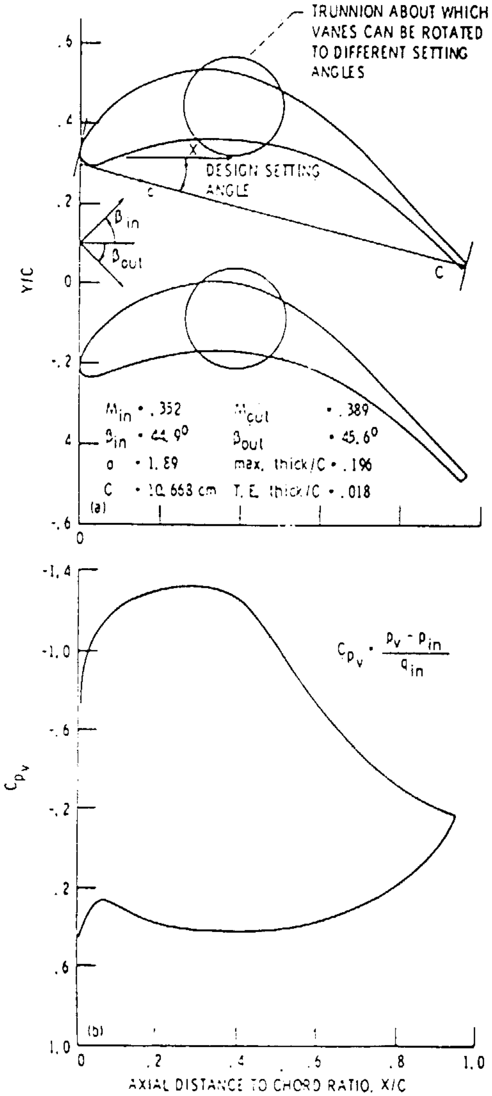
# VARIABLE INLET GUIDE VANES

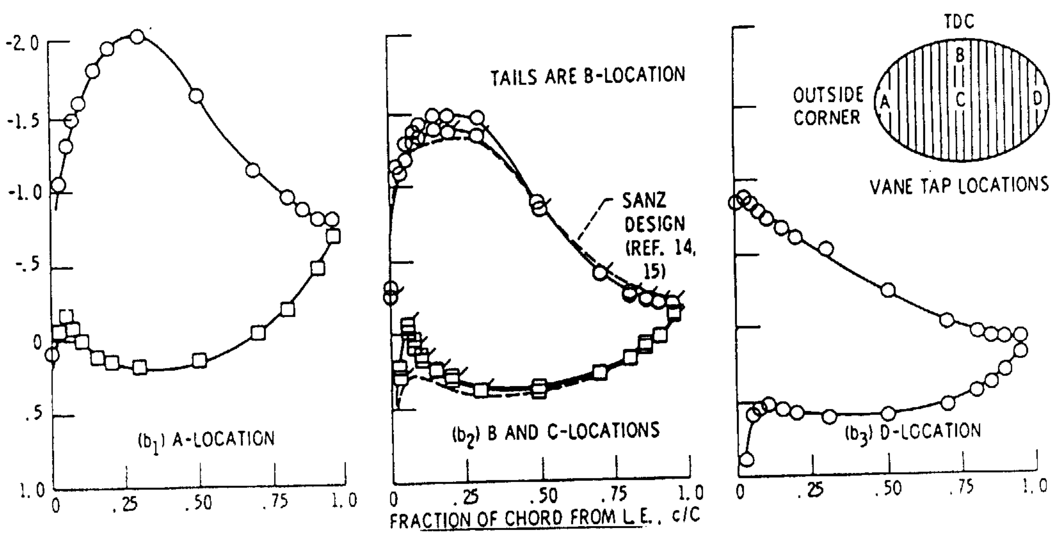





**SOURCE: Neal,J.W. et al., Report ME-TSPC-88-12,PURDUE UNIVERSITY**

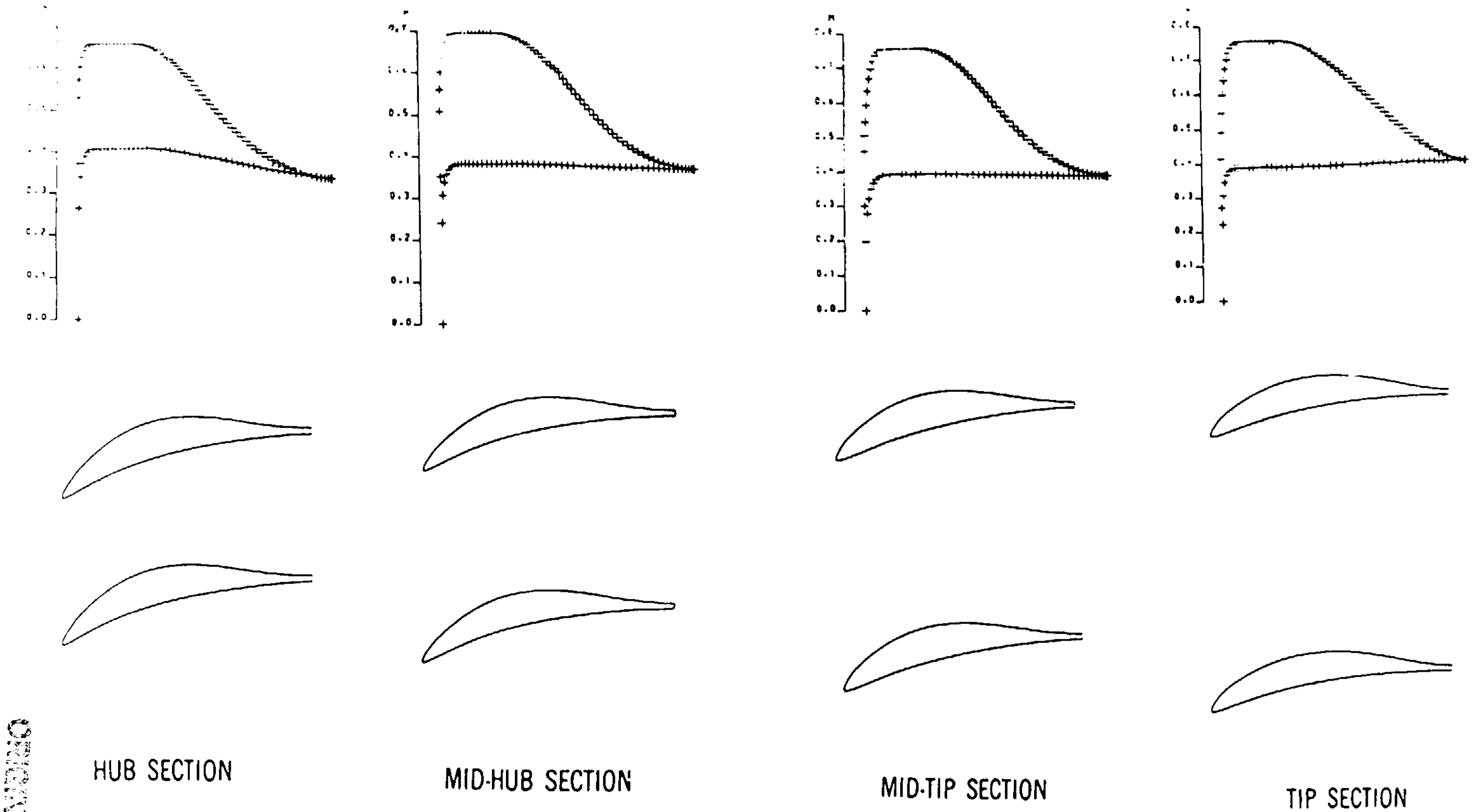
# AWT TURNING VANES



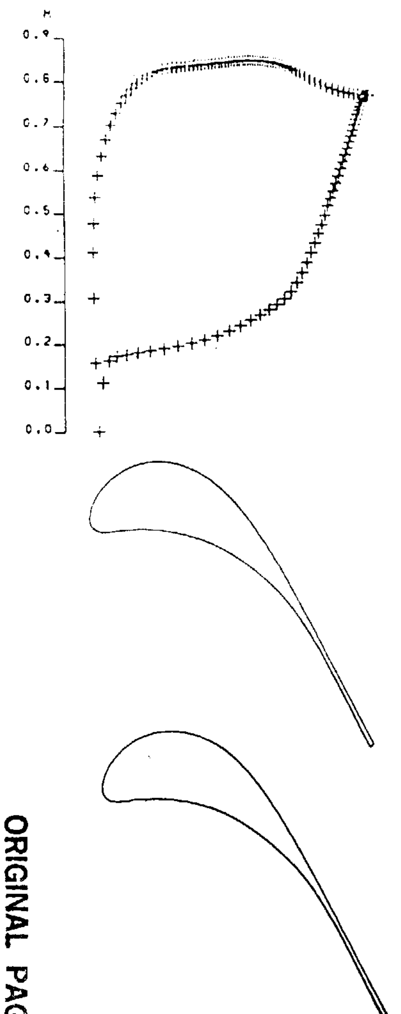




**SOURCE: Gelder, T.F. et al., AIAA Paper No. 86-0044.**

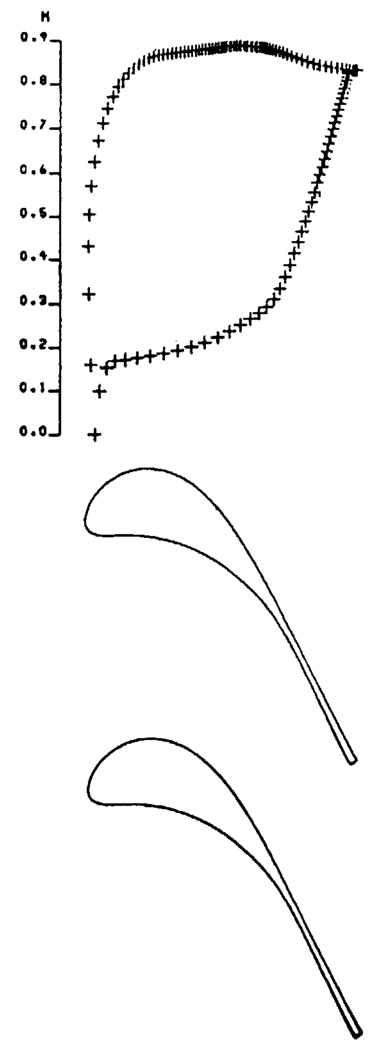
# AUTOMATED DESIGN OF COMPRESSOR STATOR BLADE




MID SPEED STATOR

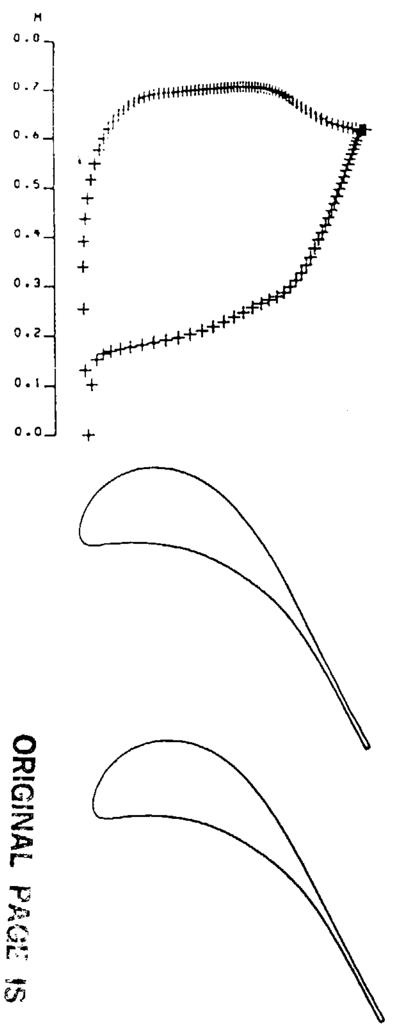


| | |
|---|---|
| M1 | 0.337 |
| BET1 | 36.39 |
| M2 | 0.782 |
| BET2 | -61.06 |
| DELB | 97.44 |
| SOL | 1.45 |
| THCR | 0.224 |
| DNTE | 0.018 |
| DSTE | -0.000 |
| TEV | 0.014 |
| LOSS | 0.005 |

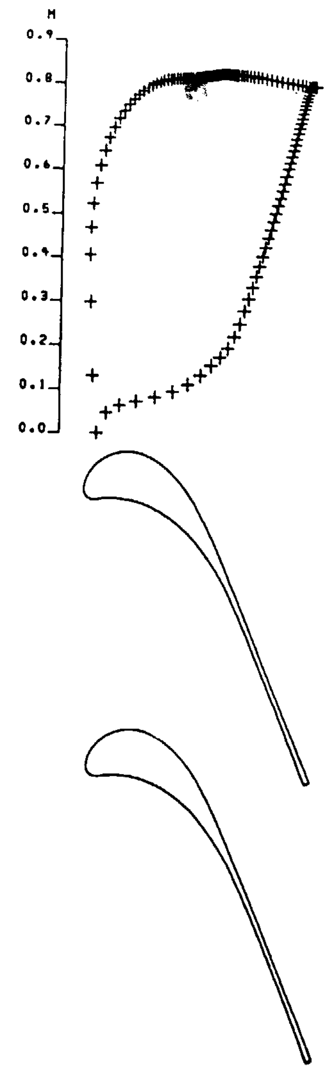



| | |
|---|---|
| M1 | 0.337 |
| BET1 | 36.38 |
| M2 | 0.839 |
| BET2 | -61.01 |
| DELB | 97.38 |
| SOL | 1.45 |
| THCR | 0.224 |
| DNTE | 0.025 |
| DSTE | -0.000 |
| TEV | 0.021 |
| LOSS | 0.005 |

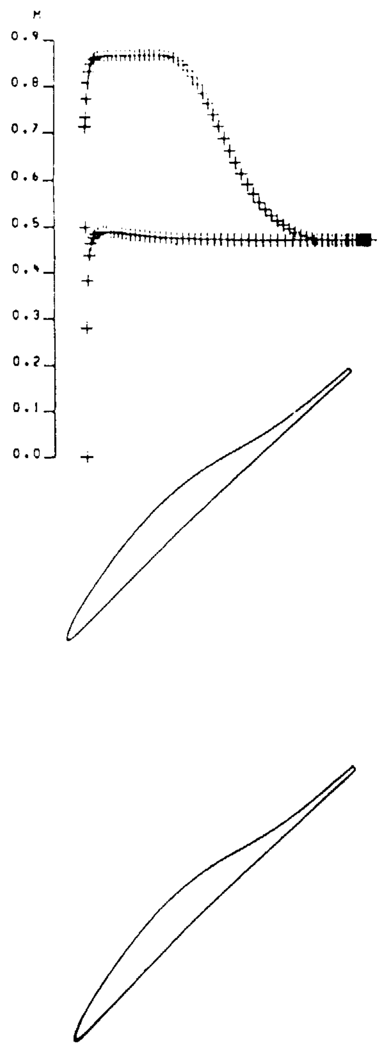
# AUTOMATED DESIGN OF TURBINE BLADE SECTIONS



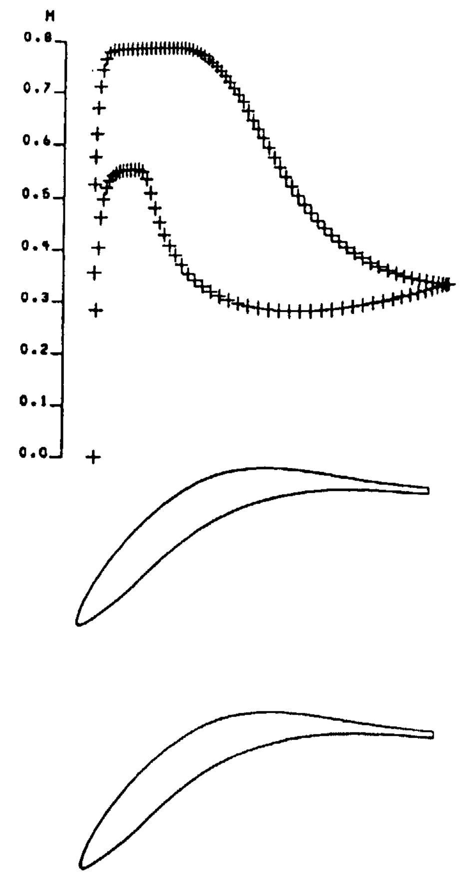

| | |
|---|---|
| M1 | 0.301 |
| BET1 | 36.41 |
| M2 | 0.629 |
| BET2 | -61.14 |
| DELB | 97.55 |
| SOL | 1.45 |
| THCR | 0.239 |
| DNTE | 0.017 |
| DSTE | -0.000 |
| TEV | 0.013 |
| .OSS | 0.006 |




| | |
|---|---|
| M1 | 0.253 |
| BET1 | 32.49 |
| M2 | 0.805 |
| BET2 | -66.74 |
| DELB | 99.23 |
| SOL | 1.43 |
| THCR | 0.186 |
| DNTE | 0.019 |
| DSTE | -0.000 |
| TEV | 0.016 |
| LOSS | 0.003 |




| | |
|---|---|
| M1 | 0.670 |
| BET1 | 52.02 |
| M2 | 0.476 |
| BET2 | 38.23 |
| DELB | 13.79 |
| SOL | 1.04 |
| THCR | 0.083 |
| DNTE | 0.020 |
| DSTE | -0.000 |
| TEV | 0.012 |
| LOSS | 0.026 |




| | |
|---|---|
| M1 | 0.600 |
| BET1 | 51.01 |
| M2 | 0.344 |
| BET2 | -3.95 |
| DELB | 54.96 |
| SOL | 1.70 |
| THCR | 0.112 |
| DNTE | 0.025 |
| DSTE | -0.001 |
| TEV | 0.016 |
| LOSS | 0.055 |