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CALCULATION OF THE ROTOR INDUCED DOWNLOAD ON AIRFOILS

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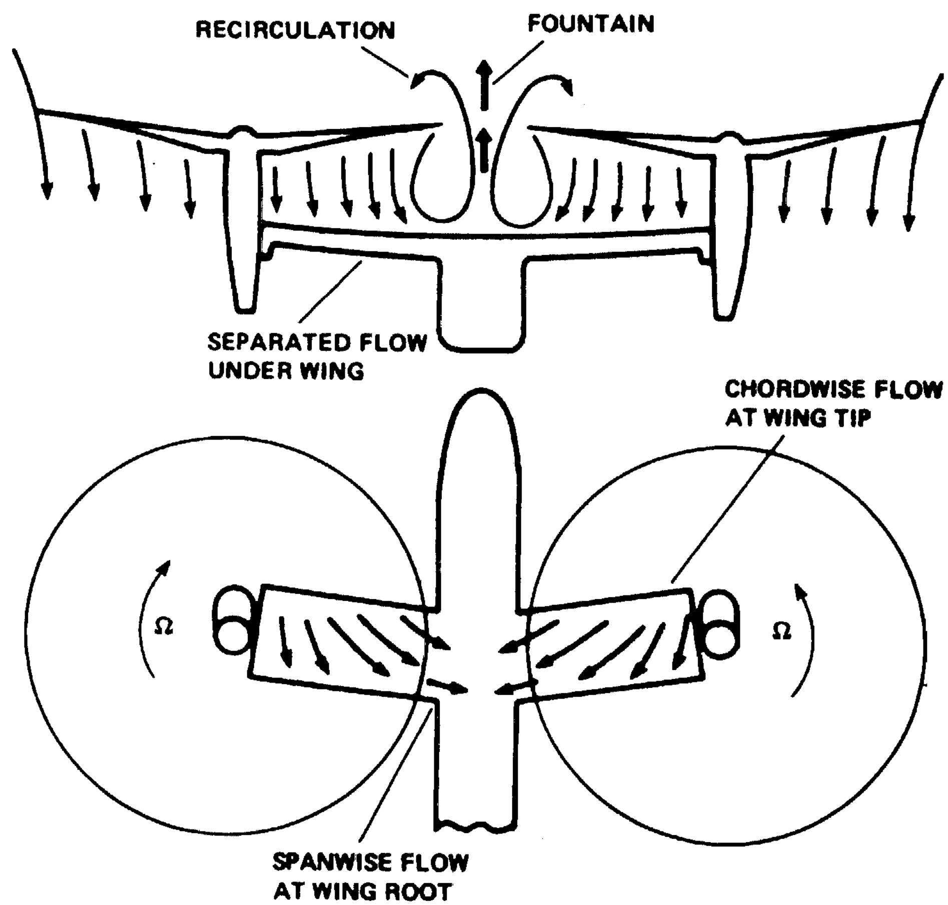
ABSTRACT

Interactions between the rotors and wing of a rotary wing aircraft in hover have a significant detrimental effect on its payload performance. The reduction of payload results from the wake of lifting rotors impinging on the wing, which is at -90 degrees angle of attack in hover. This vertical drag, often referred as download, can be as large as 15% of the total rotor thrust in hover.

The rotor wake is a three-dimensional, unsteady flow with concentrated tip vortices. With the rotor tip vortices impinging on the upper surface of the wing, the flow over the wing is not only three-dimensional and unsteady, but also separated from the leading and trailing edges.

A simplified two-dimensional model was developed to demonstrate the stability of the methodology. The flow model combines a panel method to represent the rotor and the wing, and a vortex method to track the wing wake. A parametric study of the download on a 20% thick elliptical airfoil below a rotor disk of uniform inflow was performed. Comparisons with experimental data are made where the data are available. This approach is now being extended to three-dimensional flows. Preliminary results on a wing at -90 degrees angle of attack in free stream is presented.

SCHEMATIC OF ROTOR/WING FLOW FIELD

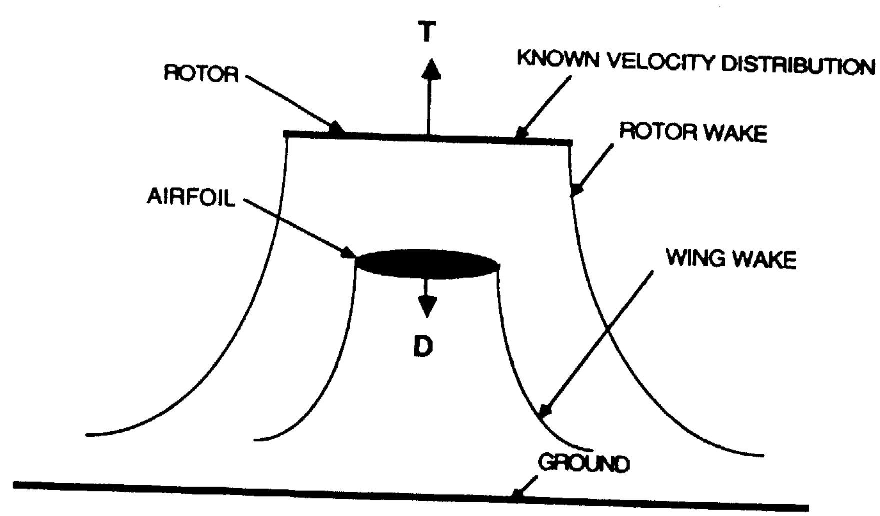


TWO-DIMENSIONAL ANALYSIS FORMULATION

- DOUBLET PANELS ON ROTOR, VORTICITY PANELS ON AIRFOIL, AND POINT VORTICES IN WAKE

- UNSTEADY CALCULATION
  --- IMPULSIVELY STARTED FLOW
  --- TIME STEPPING FOR FOLLOWING SOLUTIONS

- BOUNDARY CONDITION
  --- KNOWN NORMAL VELOCITY DISTRIBUTION ON ACTUATOR DISK
  --- CONSTANT STREAM FUNCTION ALONG AIRFOIL
  --- ZERO TOTAL VORTICITY IN FLOW FIELD



TWO-DIMENSIONAL ANALYSIS FORMULATION CONTINUED

- KUTTA CONDITION

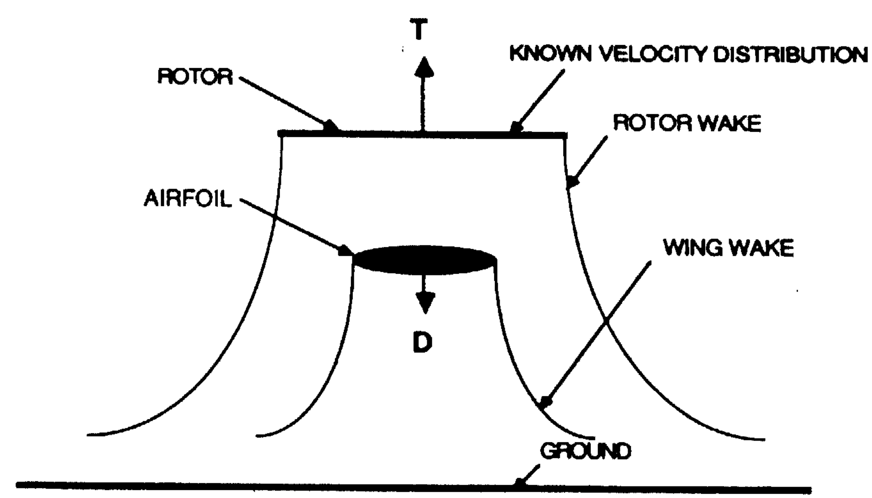
  --- ROTOR WAKE STRENGTH DETERMINED BY TOTAL PRESSURE DIFFERENCE ACROSS SLIPSTREAM : $\Gamma_r = \gamma_r V_r \Delta t$

  --- AIRFOIL WAKE STRENGTH RELATED TO STRENGTH OF BOUND VORTICITY AT SEPARATION POINT : $\Gamma_a = \gamma_s V_s \Delta t$

- TOTAL PRESSURE VARIATION ACROSS ROTOR SLIPSTREAM AND AIRFOIL WAKE

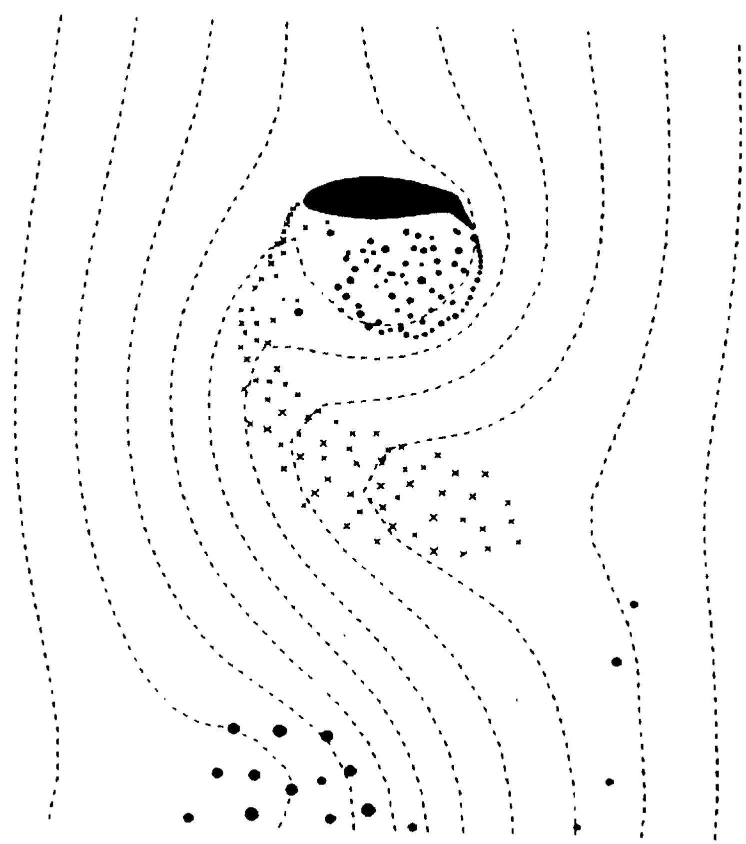
$$\Delta P_r = \rho \; V_r \, \gamma_r$$

$$\Delta P_a = \rho \; V_s \gamma_s$$



NACA 64A223 AIRFOIL (XV-15 WING) IN FREE STREAM

-90 DEGREE ANGLE OF ATTACK
25% CHORD FLAP DEFLECTED AT 45 DEGREE



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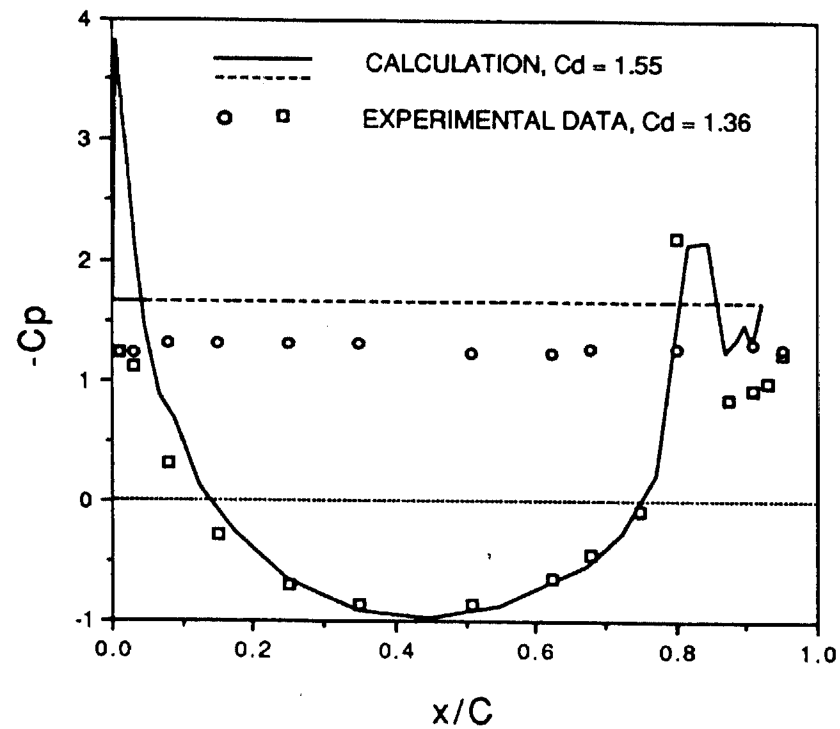
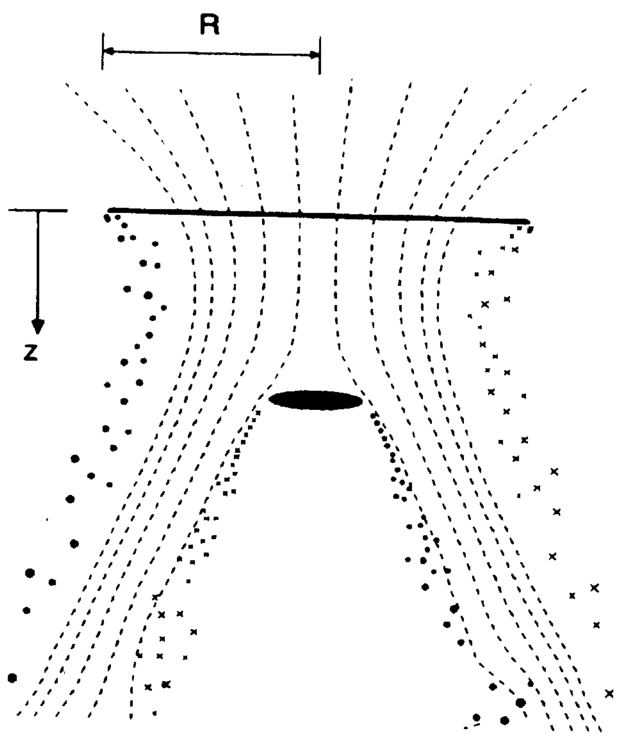
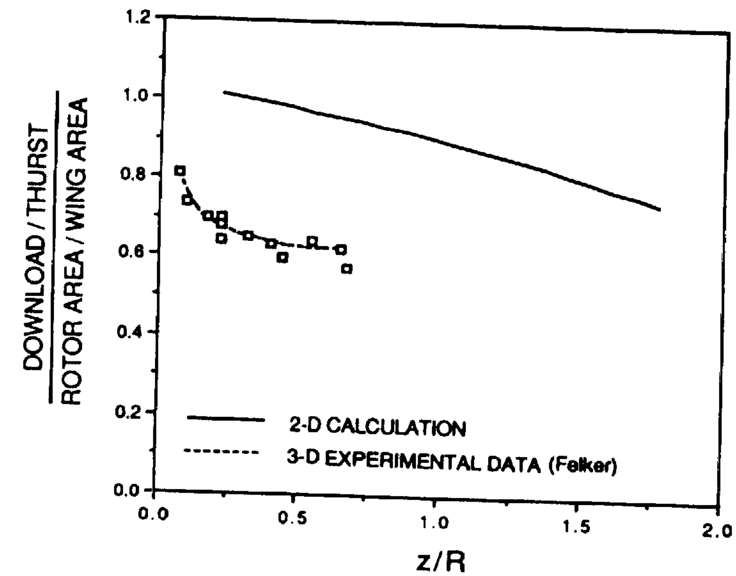


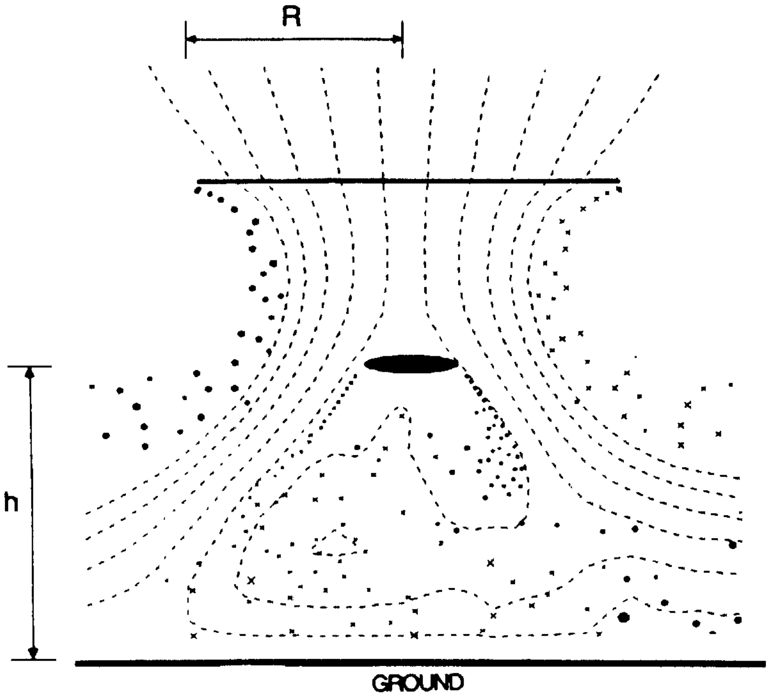
SURFACE PRESSURE DISTRIBUTION

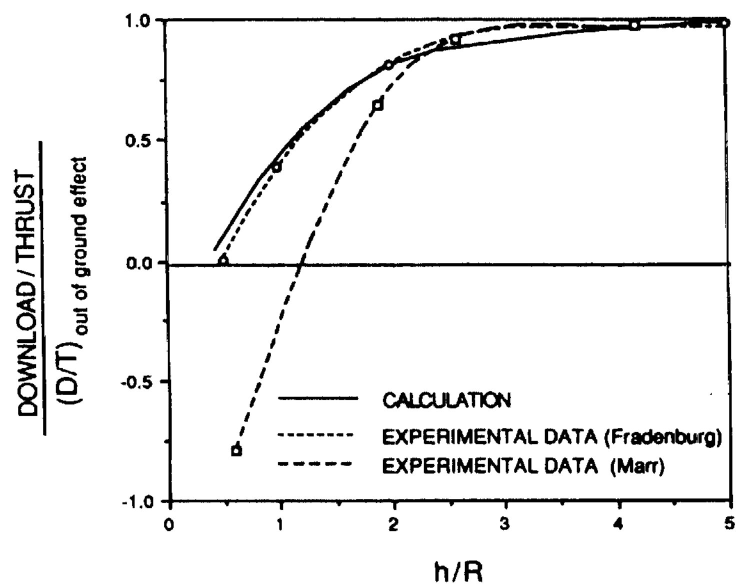
AIRFOIL/ROTOR INTERACTION : EFFECT OF ROTOR/AIRFOIL SPACING
ELLIPTICAL AIRFOIL





AIRFOIL/ROTOR INTERACTION : EFFECT OF ROTOR HEIGHT ABOVE GROUND ELLIPTICAL AIRFOIL





THREE-DIMENSIONAL ANALYSIS FORMULATION

- CONSTANT SOURCE AND DOUBLET PANELS ON WING, DOUBLET PANELS IN WAKE

- UNSTEADY CALCULATION
  --- IMPULSIVELY STARTED FLOW
  --- TIME STEPPING FOR FOLLOWING SOLUTIONS

- WAKE CORE SIZE GROWS WITH AGE

  $$r_0 \sim \sqrt{t}$$

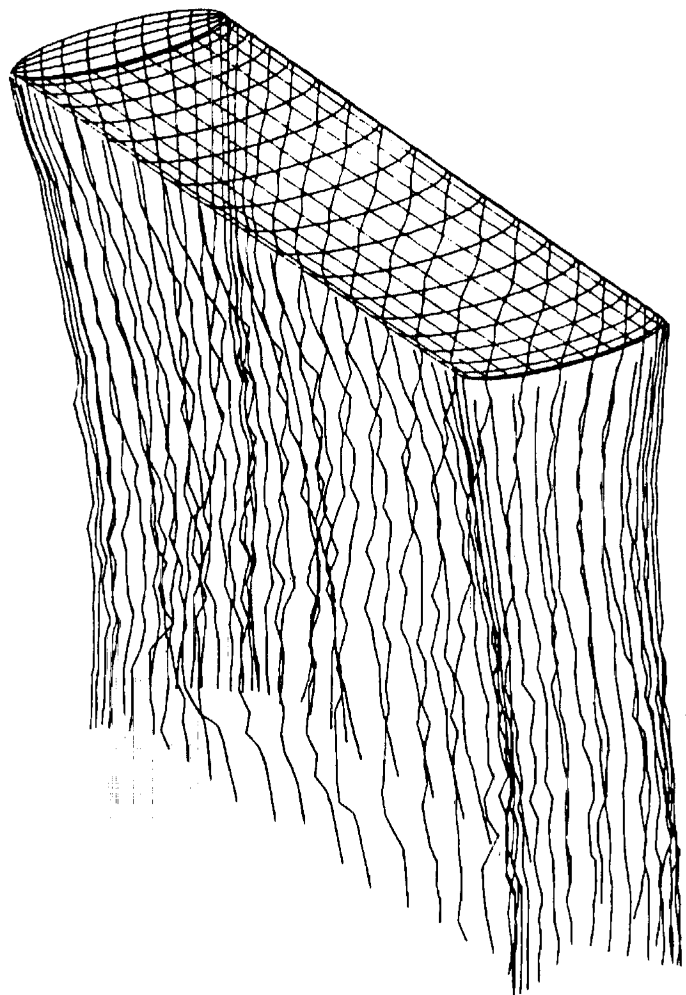
- BOUNDARY CONDITIONS
  --- FLOW TANGENCY
  --- VELOCITY POTENTIAL JUMP ACROSS BODY PANEL $=\Phi/2$

- KUTTA CONDITION

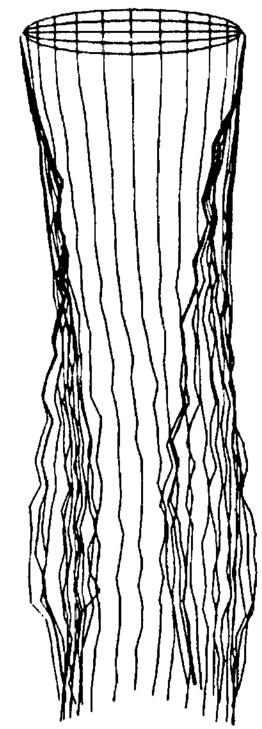
  WAKE STRENGTH, $\mu_W = \mu_U - \mu_L$

ELLIPTICAL WING IN FREE STREAM

-90 DEGREE ANGLE OF ATTACK
ASPECT RATIO =4.0

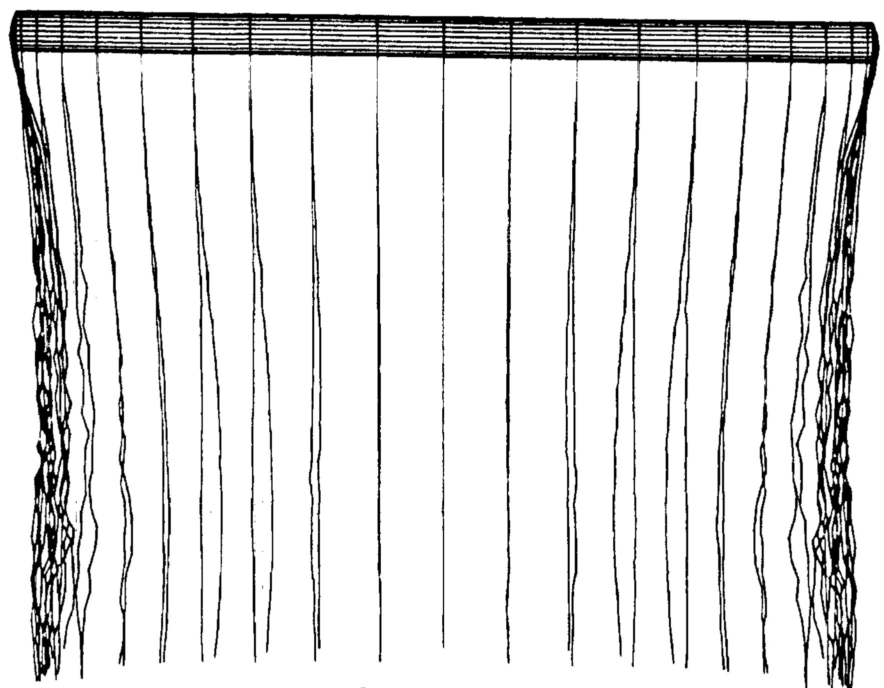


PERSPECTIVE VIEW

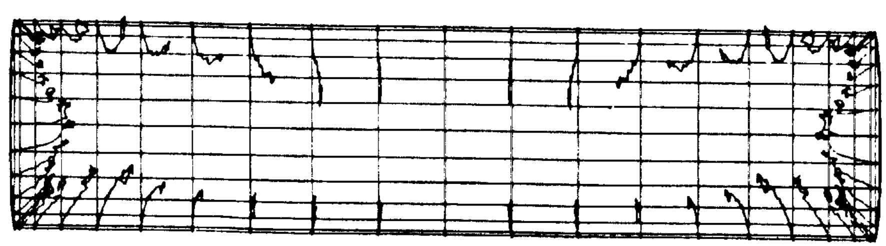


VIEW FROM WING TIP

ELLIPTICAL WING IN FREE STREAM (CONTINUED)



SIDE VIEW



VIEW FROM BENEATH

FUTURE WORK

- ROTOR MODEL

  --- ACTUATOR DISK MODEL
  LINEAR DOUBLET PANELS IN STREAMWISE DIRECTION FOR ROTOR WAKE

  --- ROTOR BLADE MODEL
  DOUBLET PANELS ON ROTOR BLADE TO INCLUDE THE EFFECT OF BLADE TWIST, AND SENSE OF ROTOR ROTATION

- WAKE MODEL

  --- AMALGAMATE AND REDISTRIBUTE WAKE PANELS TO REDUCE COMPUTATIONAL TIME

  --- DISCRETIZE FAR WAKE PANELS TO MODEL OSCILLATING WAKE