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MELBOURNE, VICTORIA

Aerodynamics Technical Memorandum 397

# DESCRIPTION OF A SIMPLE ROTOR TEST RIG AND PRELIMINARY WAKE STUDIES (U)

by

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# DESCRIPTION OF A SIMPLE ROTOR TEST RIG AND PRELIMINARY WAKE STUDIES (U)

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## SUMMARY

A simple test rig has been constructed, to obtain detailed rotor wake geometry data. The rotor head and blades have been taken from a radio-controlled model and attached to a 1HP 3-phase motor. The rotor and drive system were mounted on a rigid tripod-supported stand, and the rig used to obtain smoke flow visualization photographs of tip vortices within the rotor wake. These photographs provide vortex trajectories from which axial and radial coordinates of the vortex can be determined. The resulting data can be used to construct prescribed wake models for use in helicopter aerodynamics codes.



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**CONTENTS**

## NOTATION

| | |
|---|---|
| c | blade chord |
| CA | camera |
| HP | horse power |
| N | rotor speed |
| r | radial distance from axis of rotation |
| R | rotor radius |
| SG | smoke generator |
| t | blade section thickness |
| z | blade section camber |
| Z | axial coordinate of wake relative to rotor hub |
| $\theta$ | blade collective pitch (at the root) |
| $\psi$ | blade azimuth angle measured from smoke injection point in direction of rotation |

# 1. INTRODUCTION

For the aerodynamic analysis of a helicopter a detailed knowledge of the flow field in the vicinity of the aircraft is essential. The determination of the wake geometry and resulting flow field still remains one of the more difficult problems. The rapid advances in digital computers have made possible the adoption of the straight forward approach of representing the vortex elements trailed by each blade. In these iterative methods, which are known as free wake methods, the computational process is tedious, with uncertain convergence due to singularities introduced into the system. To avoid the need for an iterative process, the wake geometry is often specified using experimental data. These methods are known as prescribed wake methods. Parametric studies [1] have shown that the velocity field and aerodynamic loads are very sensitive to wake geometry. The present study is therefore directed towards obtaining detailed and accurate wake geometry.

A simple test rig, described herein, has been constructed. Although running at much lower speeds than full-scale rotors, it nevertheless provides an opportunity to develop some expertise in rotor testing while at the same time providing data on the location of tip vortices in the wake of a rotor. Experimental data obtained with this facility will provide opportunities for modification and further development of computer programs available at the Aeronautical Research Laboratory (ARL) for numerical studies of helicopter rotor aerodynamics.

Some impetus to this work was provided by the ABS-RW Groups's support of a final year engineering project by a RAAF cadet (Reference 2). As part of this project, initial running and development of a flow visualisation method was carried out.

# 2. DESCRIPTION

## 2.1 Location

The rig and its enclosure (Fig. 1) occupy part of an existing laboratory and are consequently influenced by other equipment and furniture. The rotor enclosure is bounded on one side by an existing wall and hardboard sheets set 0.76m above floor level form the other 3 sides. This arrangement affords some protection to personnel while allowing reasonable open area underneath for rotor inflow. The rotor induced flow is discharged upwards (the thrust acting downward) and when using smoke as flow tracer a roof vent fan is operated to reduce contamination and flow recirculation. Mention will be made later (see Discussion) of the likely effect of having to position the enclosing walls so close because of space limitations.

Initially the rig had been run in an outside location but the presence of ambient winds and high ambient light levels precluded smoke flow studies. Hard anchor points in this situation however allowed running at higher tip speeds.

## 2.2 Rotor

The rotor and drive system is mounted on a rigid tripod-supported stand (Fig. 2) and may be levelled by three 19 mm jacking screws bearing directly on the concrete floor. No attachment to anchor points has been found necessary for rotor speeds up to 450 rpm. The central spindle of the stand may be traversed vertically and azimuthally and then locked.

A mounting plate, attached to the spindle, carries the 1HP 3-phase motor with the shaft and spindle axes coincident. A VARIAC Autotransformer is used to control the speed of the motor. An attachment piece (Fig. 3) transmits the motor torque to the rotor head and blades, which are taken from a radio controlled Hirobo SST Jet Ranger model helicopter. The 'paddle' blade stabilizer has been removed and collective pitch is set prior to a run by means of locknuts clamping the pitch change rods.

Relevant dimensions are:-

| | |
|---|---|
| Rotor radius (R) | 775 mm |
| Blade chord (c) | 55 mm |
| Section-thickness (t) | 15% at 25% chord |
| -camber (z) | 2.5% |

The precise designation of this aerofoil section is not known.

# 3. INSTRUMENTATION

### 3.1 General Radio Strobotac

A repetitive light source which measures rotor speed and when running at blade frequency allows blade tracking to be checked. When triggered externally by a special unit (see Section 4) the flash strobing will occur at selected blade azimuths [3].

### 3.2 TEM Engineering Smoke Generator

Used for smoke flow visualization of tip vortices within the rotor wake. Oil flow rate and vapourizer heating current controls allow adjustment of smoke density.

### 3.3 Camera

Hasselblad 500 EL/M Motor driven camera using 120 film (12 exposure). Lenses of 80 and 150 mm focal length.

3.4 Azimuth-Selectable Flash Synchronizer (ASFS)

This unit has been designed and built at ARL and relevant details are given in Reference 3. Briefly, the X-contact closure which normally triggers a flash unit, instead initiates a count-down of pulses. These pulses are generated by a slotted disk (72 slots at 5 degree intervals) attached to the rotor drive shaft. A thumb-wheel switch sets the required number of pulses for completion of count-down, thus triggering the flash unit at a known blade azimuth.

This unit also triggers the Strobotac, if required for strobe illumination at specified blade azimuth.

## 4. EXPERIMENTAL RESULTS AND DISCUSSION

The main purpose of these tests was to obtain data regarding the disposition of tip vortex cores in the wake as a function of blade azimuth.

The most recent photographs at specific azimuthal blade positions are shown in Figs. 4,5,6 and 7. Six shots at $\psi = 0^{\circ}$ are presented in order to give some indication as to the variability of the flow. The remaining shots are for $\psi = 45^{\circ}, 90^{\circ}, 135^{\circ}$ respectively.

Rotor operating conditions were:-

| | |
|---|---|
| Speed (N) | 250 rpm |
| Blade pitch ($\theta$) | 4.5 degree |
| Smoke injection | Rotor plane (Z/R=0) |
| | Radial position (r/R=1.02) |

Where r and Z are the radial and axial coordinates of the wake relative to the rotor hub. Under the test conditions the thrust/solidity is close to full-scale flight, although the tip Mach number is well below full-scale values.

Photographs presented in figures 4,5,6 and 7 show with explicit detail the formation and growth of tip vortices in the wake. Generally, three vortex cross sections are visible prior to vortex diffusion. Photographs in figures 5 and 6 confirm earlier observations[4] that the initial rate of axial displacement of the tip vortices is small.

The six photographs presented in figure 4 show the unsteady nature of the flow. The radial and axial coordinates of the first tip vortex (i.e. tip vortex immediately above the blade) vary about ±30% and ±20% respectively relative to their mean value. These variations in terms of rotor radius are about ±0.016R in the radial direction and ±0.025R in the axial direction. The above variations are much higher than Landgrebe's observations[4], where variations in measured radial and axial coordinates were generally within ±0.01R. This indicates that for quantitative flow analysis, the quality of the flow would have to be improved. At present the unsteadiness of the flow can be attributed to such factors as the existence of drafts in the test area, and obstacles such as walls, floor and ceiling in the flow region. The effect of these factors on the rotor flow field are not well understood, nor can they be reliably predicted[5]. A larger and versatile experimental facility is currently being built to test model helicopter rotors in hover[6]. This facility will hopefully provide interference free flow in the test region.

## 5. CONCLUDING REMARKS

A rotor test rig has been constructed and used successfully to obtain the distribution of vorticity in the wake of a rotor. Photographs presented in this report show the detail with which tip vortex trajectories are visualized. Photographs also show the data scatter caused by wake unsteadiness. Even small flow disturbances will aggravate these unsteady problems. In the absence of correction factors to account for these disturbances the quality of the flow would have to be improved, a large number of photographs should be acquired at each operating condition, and the resultant vortex measurements should be averaged.

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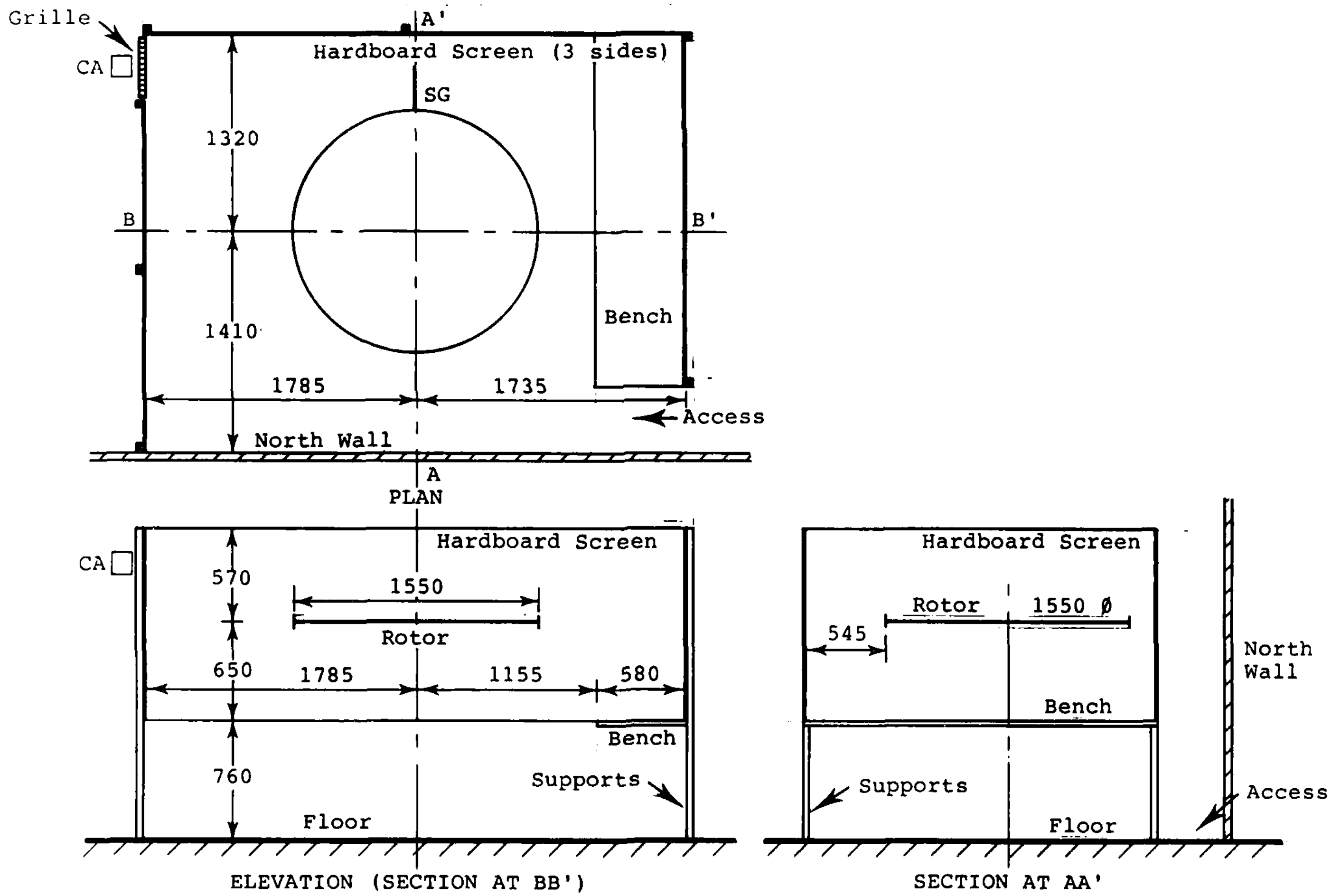



FIG. 1 GENERAL LAYOUT OF TEST RIG AND ENCLOSURE

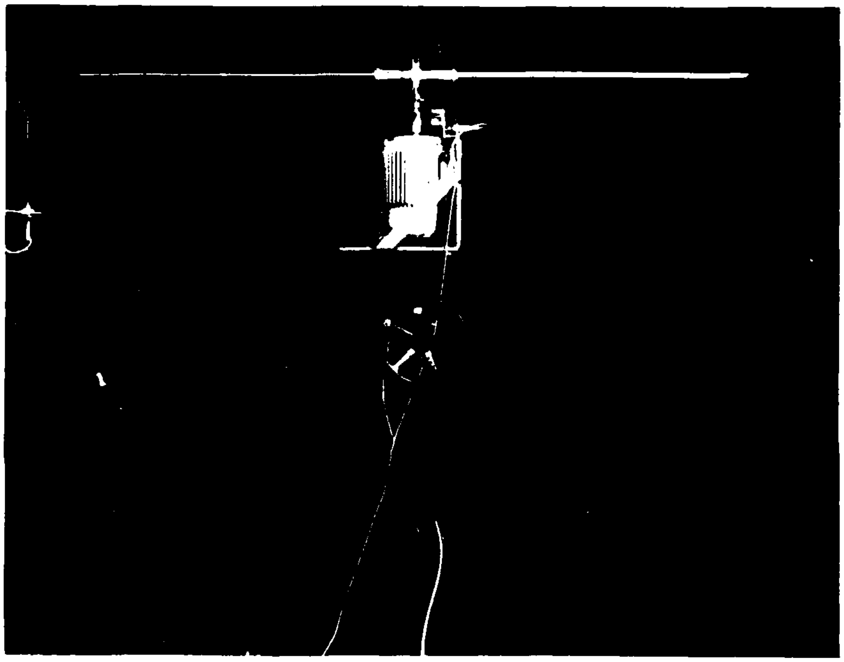


FIG. 2 TEST RIG

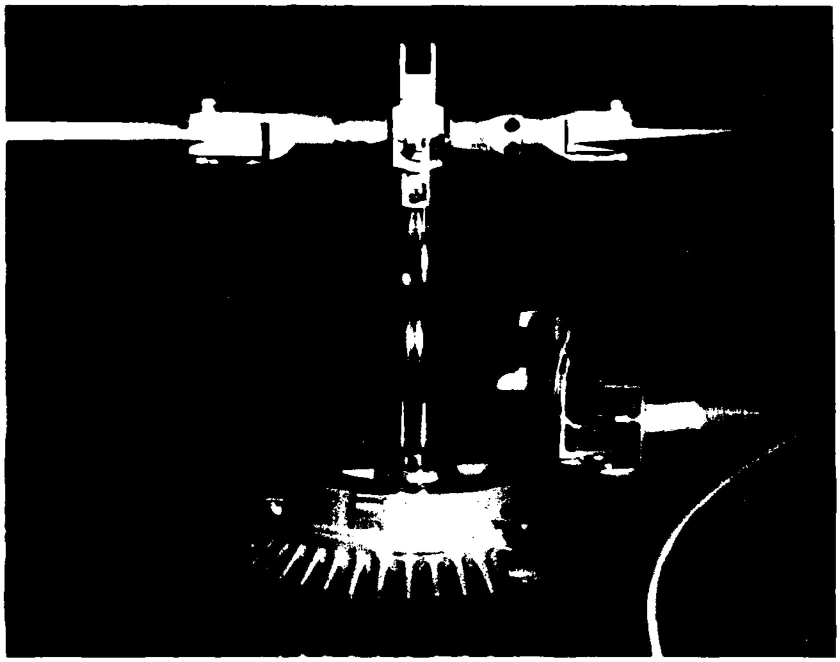


FIG. 3 CLOSE UP VIEW OF ROTOR HEAD, COLLECTIVE PITCH CONTROL, COUPLING PIECE, AND SLOTTED DISK

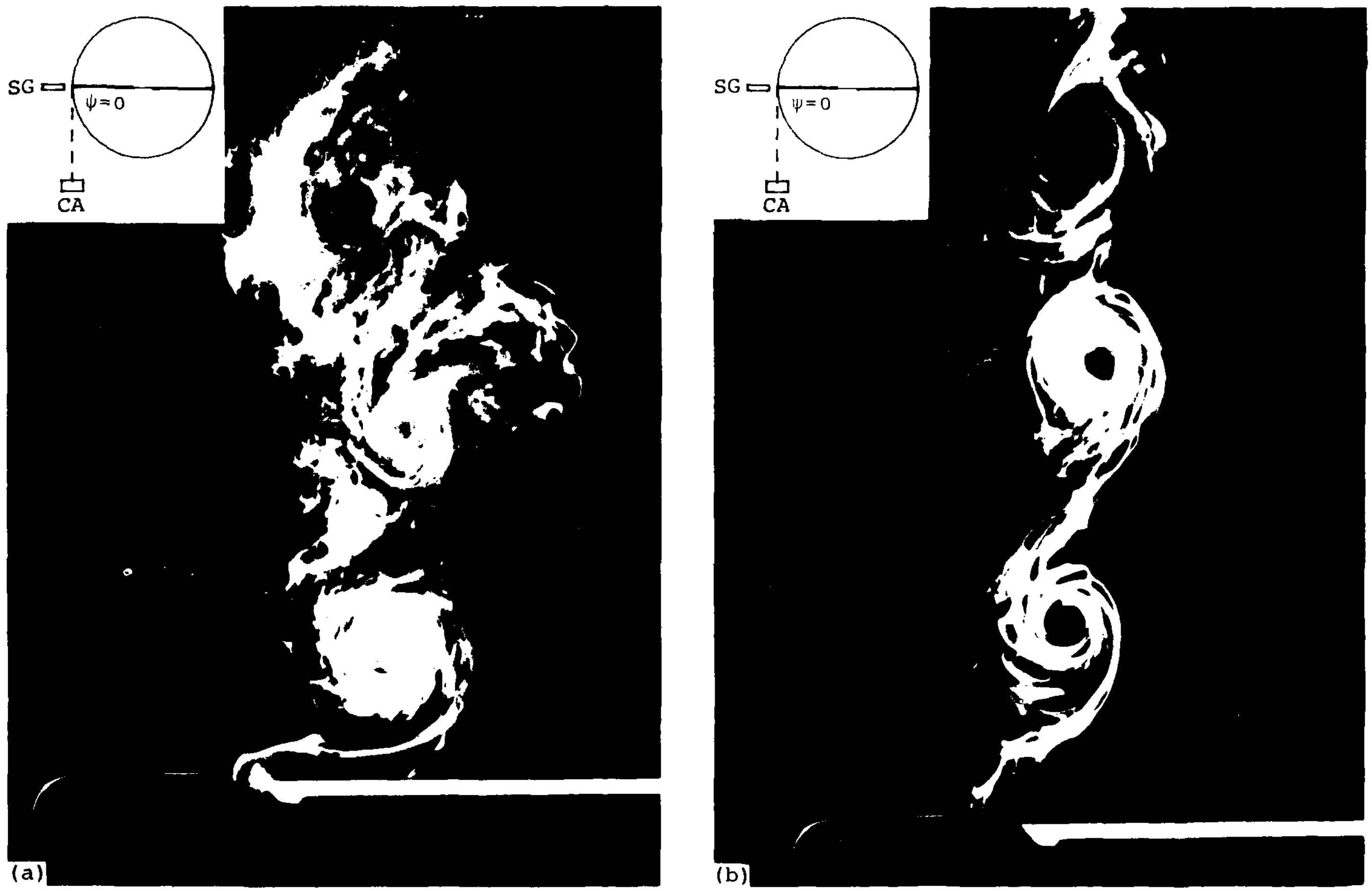
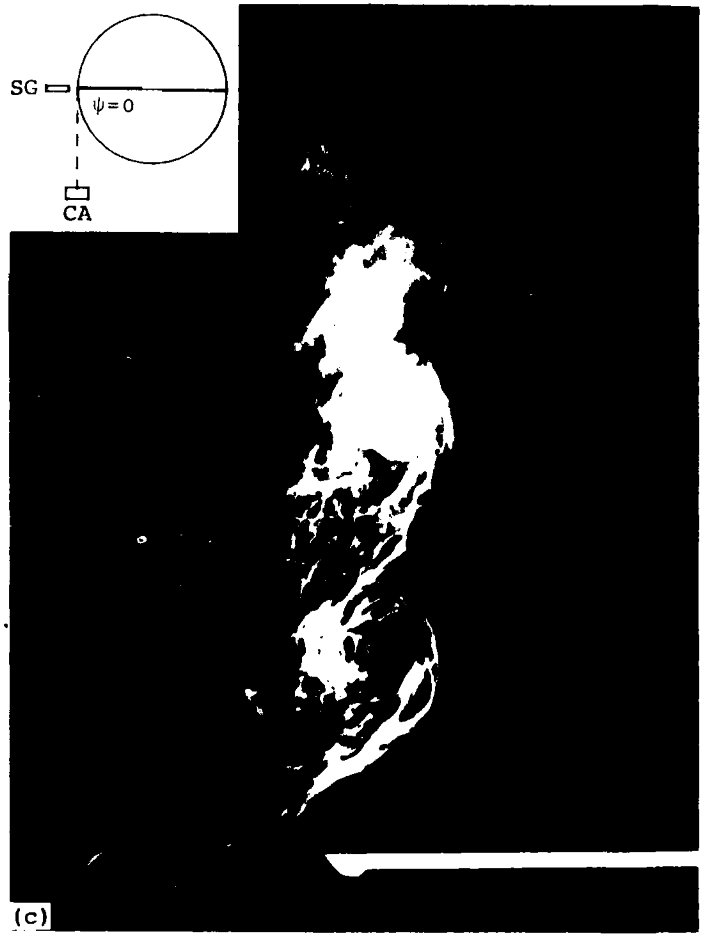



FIG. 4 SMOKE-FLOW VISUALIZATION OF TIP VORTICES $\psi$ = 0.0



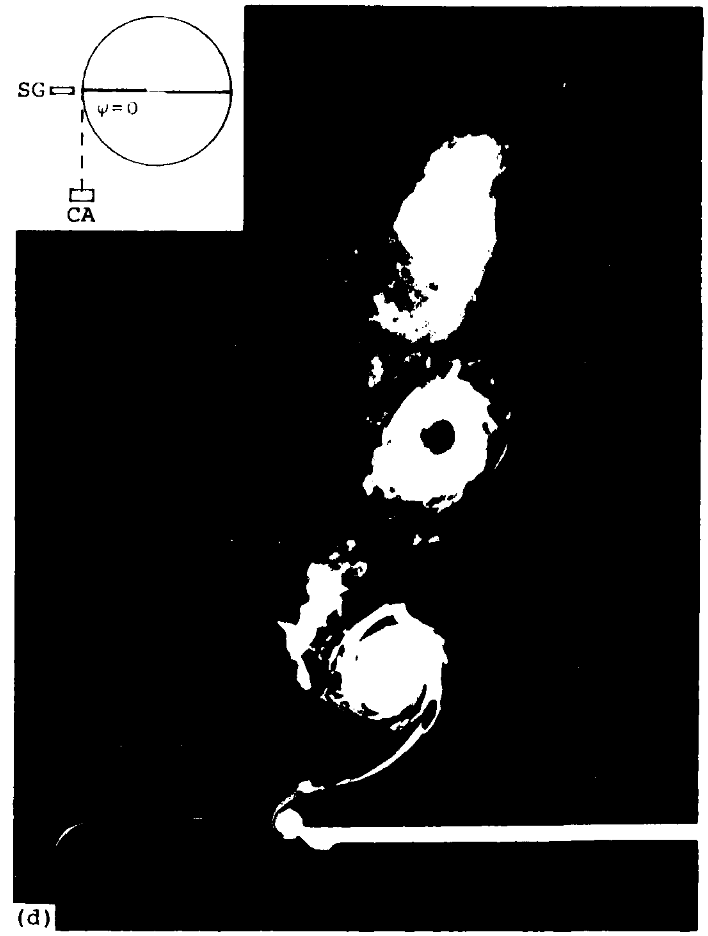




FIG. 4 (CONTINUED)

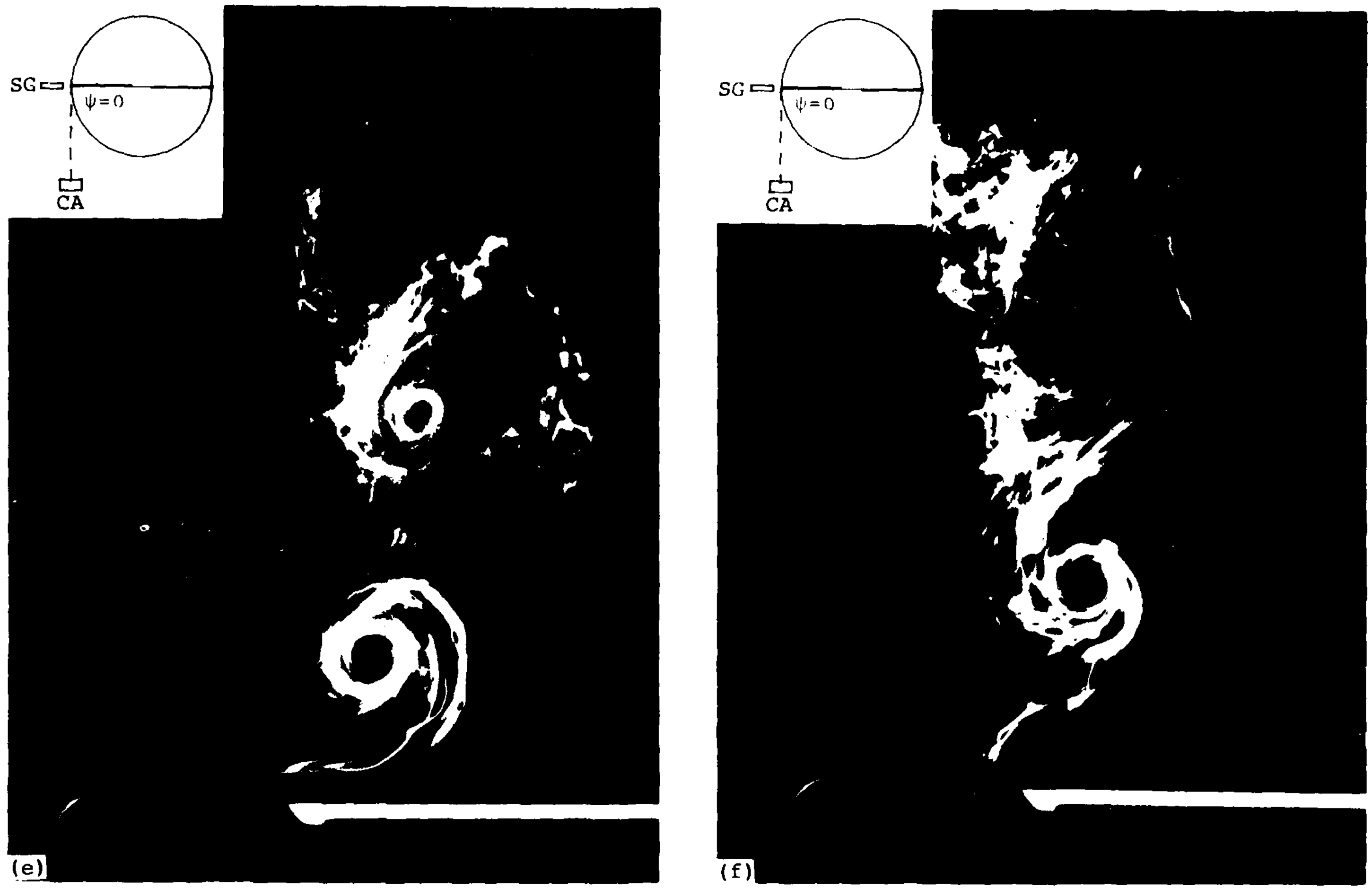



FIG. 4 (CONTINUED)

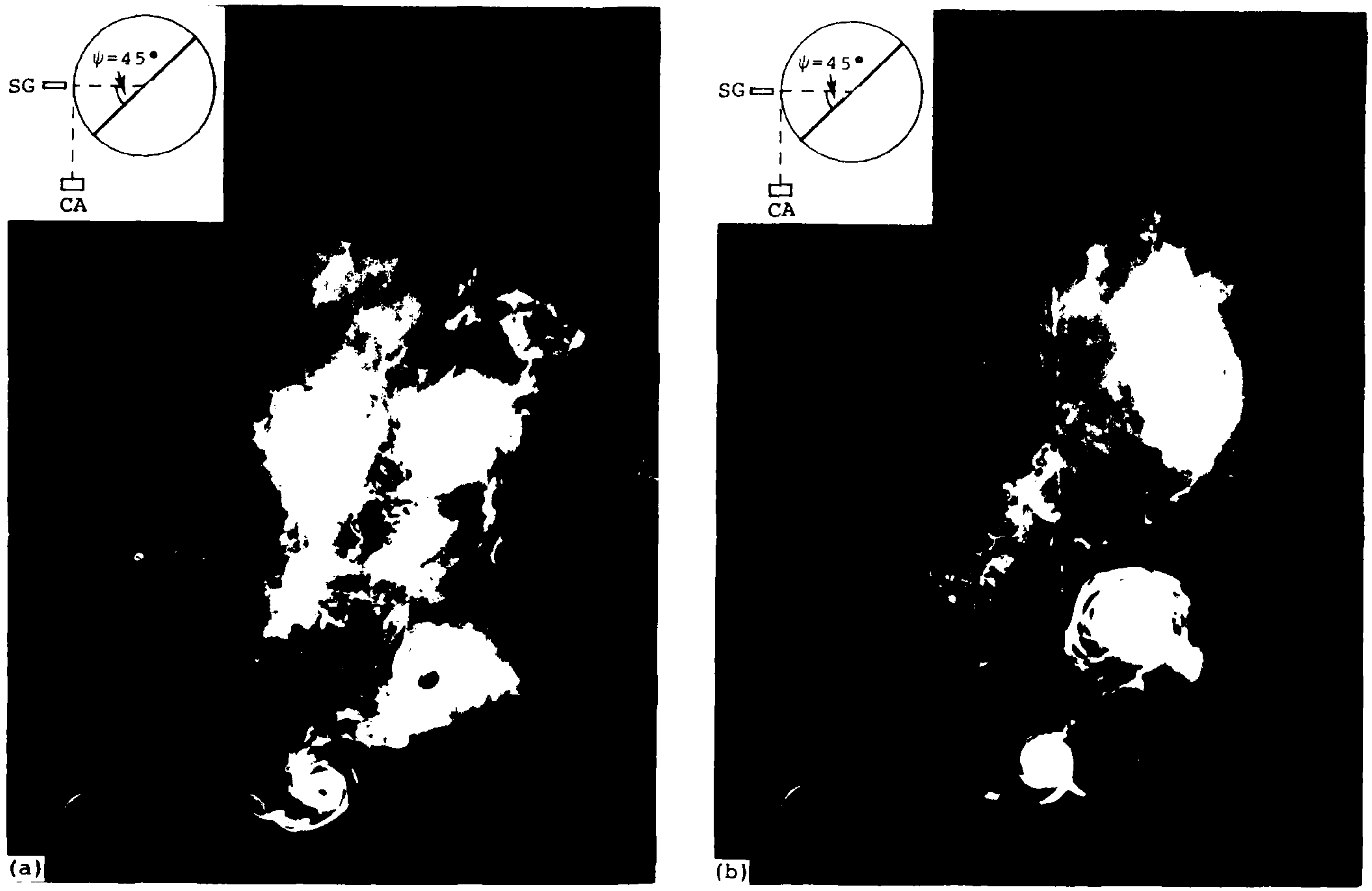



FIG. 5 SMOKE-FLOW VISUALIZATION OF BLADE TIP VORTICES $\psi = 45°$

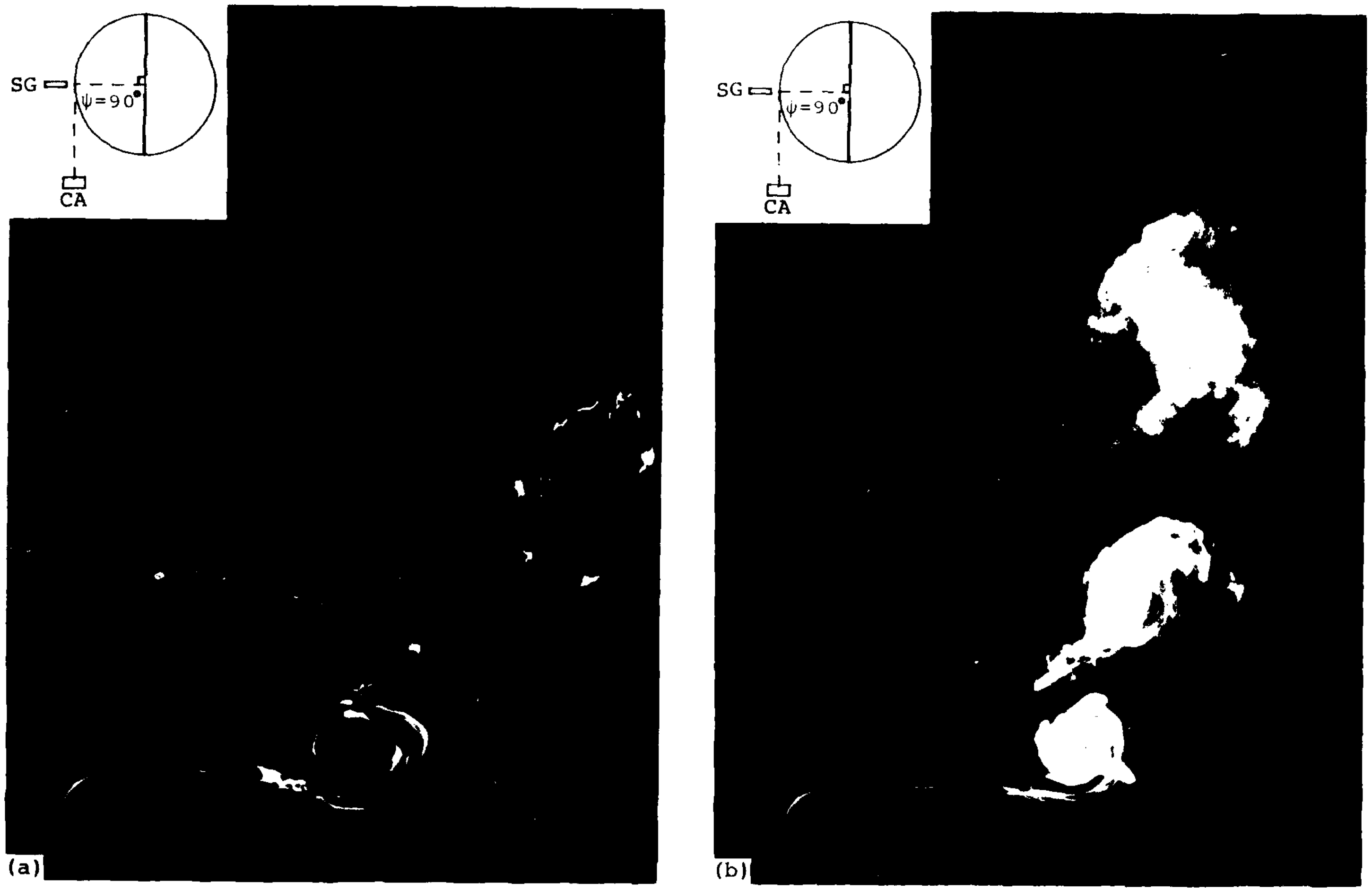



FIG. 6 SMOKE-FLOW VISUALIZATION OF BLADE TIP VORTICES $\psi$ = 90°

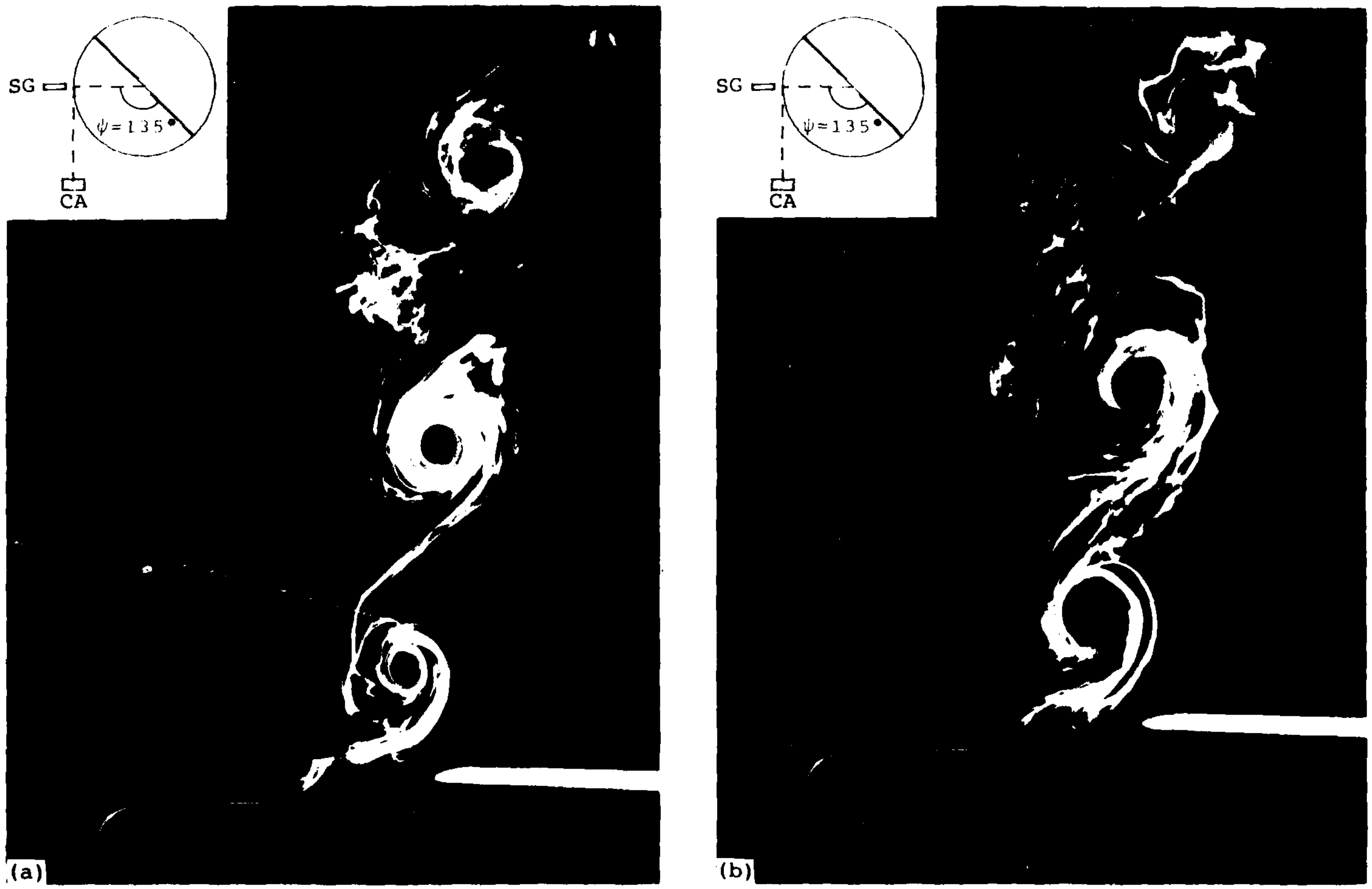



FIG. 7 SMOKE-FLOW VISUALIZATION OF BLADE TIP VORTICES $\psi$ = 135°

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