Semi-Annual Progress Report

on

COMPRESSOR AND FAN WAKE CHARACTERISTICS

(NASA-CR-143172) COMPRESSOR AND FAN WAKE CHARACTERISTICS Semiannual Progress Report, period ending 30 Jun. 1975 (Pennsylvania State Univ.) 10 p HC $3.25 CSCL 20D

N75-27310

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by

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July 1975

1. STATEMENT OF THE PROBLEM

Both the fluid dynamic properties of a compressor rotor, governing efficiency, and the acoustical properties, governing the radiated noise, are dependent upon the character of the wake behind the rotor. There is a mixing of the wake and the free stream and a consequential dissipation of energy, known as mixing loss. The operational rotors generate the radial component of velocity as well as the tangential and axial components and operate in a centrifugal force field. Hence a three-dimensional treatment is needed.

The objective of this research is to develop an analytical model for the expressed purpose of learning how rotor flow and blade parameters and turbulence properties such as energy, velocity correlations, and length scale affect the rotor wake characteristics and its diffusion properties. The model will necessarily include three-dimensional attributes. The approach is to employ, as information for the model, experimental measurements and instantaneous velocities; and turbulence properties at various stations downstream from a rotor. A triaxial probe and a rotating conventional probe, which is mounted on a traverse gear operated by two step motors, will be used for these measurements. The experimental program would include the measurement of mean velocities, turbulence quantities across the wake at various radial locations and downstream stations. The ultimate objective is to provide a rotor wake model, based on theoretical analysis and experimental measurements, which the acousticians could use in predicting the discrete as well as broadband noise generated in a fan rotor. This investigation will be useful to turbomachinery aerodynamists in evaluating the aerodynamic losses, efficiency and optimum spacing between a rotor and stator in turbomachinery.

2. PROGRESS REPORT

This is a brief informal semi-annual progress report on the work accomplished during the period ending June 30, 1975.

2.1 Theoretical Analysis:

Two approaches are presently being pursued for the analysis of the rotor wake. The first approach involves the solution of rotor wake equations in three dimensional rotating cylindrical coordinate system. The assumption of wake similarity is retained as in earlier analyses. The preliminary results indicate that the tangential component (relative) of the wake defect decays faster than the defects in axial and the radial components. This seems to indicate that the wake center line is appreciably curved as it travels downstream. This curvature should have appreciable effect in subsequent decay of the wake as well as turbulence properties (intensities and stresses) of the wake. We feel that the curvature and rotation effects are mainly responsible for the rotor wake being appreciably different from a cascade or an isolated aerofoil wake.

The second approach is based on the momentum integral approach. In this method the equations are integrated in the tangential direction and the similarity in wake profiles are assumed. Attempts are being made to solve the resulting four ordinary differential equations to provide expressions for the decay characteristics of three components (tangential, axial and radial) of wake defect at the center line as well as rate of spreading (wake thickness).

2.2 Experimental Program:

The work completed in this category can be classified as:

(1) Interpretation of the wake data taken from a stationary three

dimensional probe and completed in June 1974.

(2) Measurement of the rotor wake using rotating hot-wire (tri-axial) and pitot probes. The measurement of the wake at mid-radius at the exit of the fan at Applied Research Laboratory has been completed and the data is being presently processed. The wake was measured at zero and 10° incidence at mid-radius. A summary of the experimental program completed so far is given in Table I.

(3) Completion of the axial flow compressor facility at the department of Aerospace Engineering.

Brief description of items (2) and (3) follows, detailed interpretation of stationary probe data (item 1) will be incorporated in reports and papers under preparation and listed in Section 2.3.

We have processed only the rotating pitot probe data so far and the results are given in Figure 1, 2 and 3. The measurements were taken at s = 0.27", which corresponds to a non-dimensional streamwise distance (s/c) of 0.045. The stagnation pressure coefficient (based on blade tip speed) is plotted in Figure 1. The stagnation pressure deficiency at the wake centerline is nearly 90 percent at mid-radius and 60 percent at $r/r_t = 0.813$. The static pressure distribution at corresponding location, shown in Figure 2, indicate a deficiency of 20 percent at the wake centerline. The velocity profile across the wake is plotted in Figure 3. The velocity defect at the wake centerline is approximately 20 percent and 10 percent at r/rt = 0.72 and 0.813 respectively. It is evident from these measurements that the static pressure variation is appreciable across the wake and hence earlier interpretation due to Klein [1], based on stagnation pressure measurement alone, are not reliable. The wake defect is small even at s/c = 0.045, a confirmation of earlier measurements from stationary probe [2].

The defect in centerline velocity measured at Penn State [2], UFER [3], Hanson [4] are plotted in Figure 4. This clearly reveals that the wake decays very rapidly in the viscinity of the blade trailing edge, and the decay rate is considerably slower beyond this.

The construction of the axial flow compressor facility was completed before March, 1975, but the shake down tests indicated appreciable inbalance at higher speeds (> 1300 RPM). Hence, the facility was disassembled to balance the rotor and to incorporate the rotating traversing facility for wake measurements. The rotor traverse gear assembly is presently being balanced at the Applied Research Laboratory.

2.3 Publications and Presentations:

Publications:

(1) R. Raj and B. Lakshminarayana, "Three Dimensional Characteristics of Turbulent Wakes Behind Axial Flow Turbomachinery, ASME Paper 75-GT-1 (March 1975), to be published in J. Engineering for Power.

(2) R. Raj, "A Form of Turbulence Dissipation Equation for Application to Curved and Rotating Turbulent Flows," to be published in Physics of Fluids, 1975.

Publications in Preparation:

(3) B. Lakshminarayana, "The Nature of Unsteady and Steady Distortions Caused by Rotor or Stator Blade Wakes," for AGARD-NATO Meeting.

(4) R. Raj and B. Lakshminarayana, "Experimental Investigation of Turbulent Wakes Behind Axial Flow Compressor Rotor," for publication by NASA.

Presentations:

(1) "Three Dimensional Characteristics of Turbulent Wakes Behind Axial Flow Turbomachinery," ASME Gas Turbine Div., March 1974, Houston, Texas.

2.4 References:

1. A. Klein, "Comparative Measurements Behind a Compressor Rotor With a Space-Bound and Co-Rotating Cylinderical Probes," Forsch IM. Ingenieurwesen, Vol. 40, No. 1, 74, P25-34 (English Translation NASA TTF-15833).

2. R. Raj and B. Lakshminarayana, ASME Paper, 75-G1-1.

3. H. Ufer, "Analysis of the Velocity Distribution at the Blade Tips of Axial Flow Compressors," Tech. Mitt Krupp (Forschungsberichte), Vol. 26, No. 2, Oct. 1968, p. 33-45 (English Translation, NASA TTF-16 366).

4. D. B. Hanson, "Noise and Wake Structure Measurements in a Subsonic Tip Speed Fan," NASA CR 2323, Nov. 1973.

TABLE I

AFRF Rotor Wake Program (Completed)

Speed of Rotation	1010 RPM	Blade Prof: Circular
Solidity at Mid Radius	1.48	Arc British C1 Profile
Stagger Angle at Mid Radius	45°	Max Thickness: 0.10
No. of Blades	12	at 0.33 Chord
Tip Radius	10.75"	Blade Chord 6"
Hub/Tip Ratio	0.44	Blade Span 5.9"

Operating Conditions

	Stationary 3D Hot Wire	Rotating 3D Hot Wire	Static & Stagnation Probe-Rotating
(1) Flow Coefficient (MR)	0.676	0.676, 0.52	0.676, 0.52
(2) Incidence (MR)	0.77°	0.77°, 10°	0.77°, 10°
(3) Loading Coeff (ψ_T)	-0.089	-0.089, 0.1118	-0.089, 0.1118
(4) Local Radius (r/r_t)	0.488, 0.535, 0.58 0.628, 0.72, 0.7666 0.815, 0.86	0.72	0.72, 0.751
(5) Axial Station (s/c)	5 Axial Stations (TE to 1.4) 40 Wakes	0, 0.045, 0.089 6 Wakes	0, 0.045

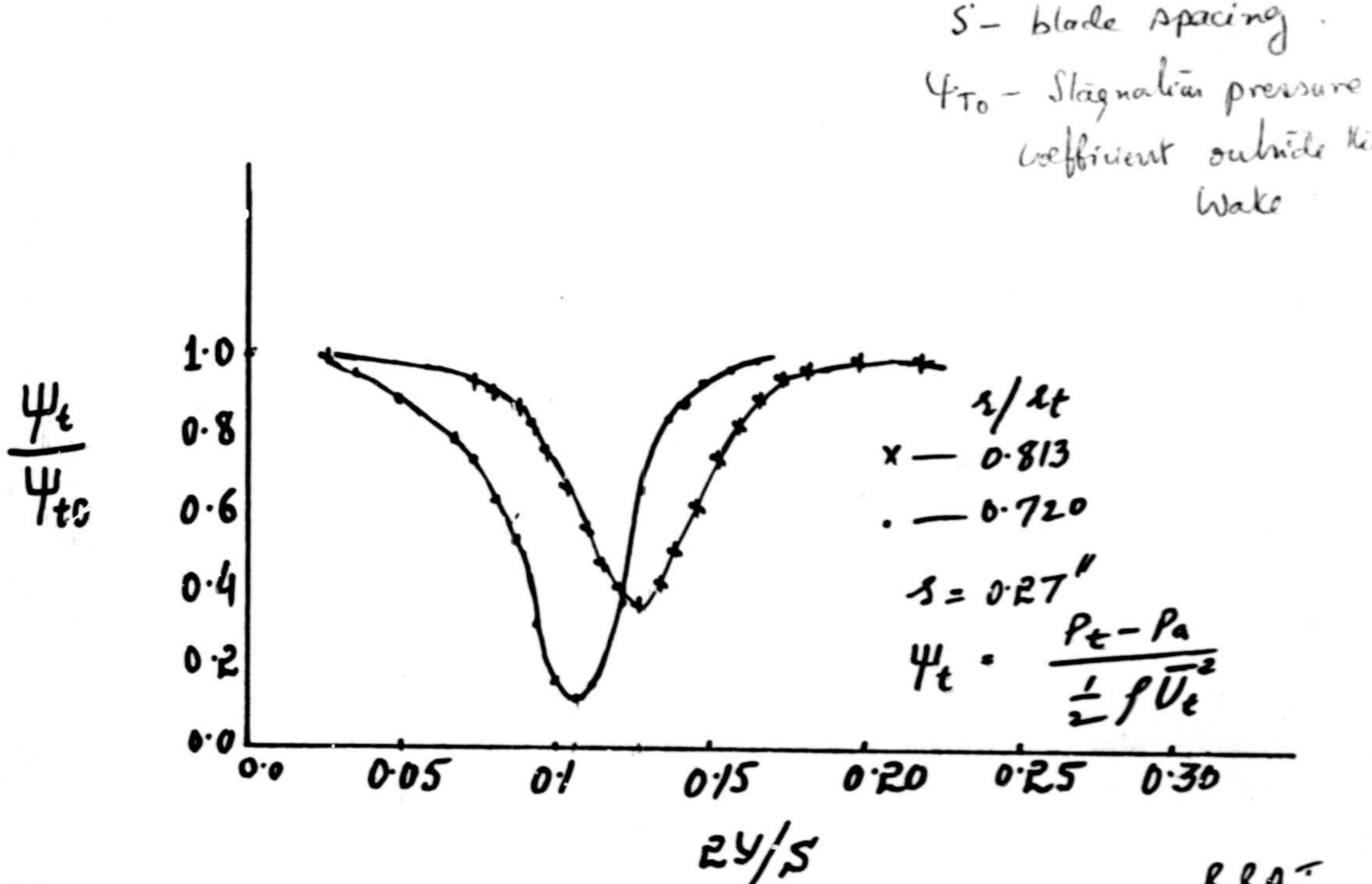

Fig. 1 Distribution of Stagnation Pressure Coefficient Across the Wake, s/c = 0.045, 12 Bladed Rotor at AFRF Facility, zero degree incidence.

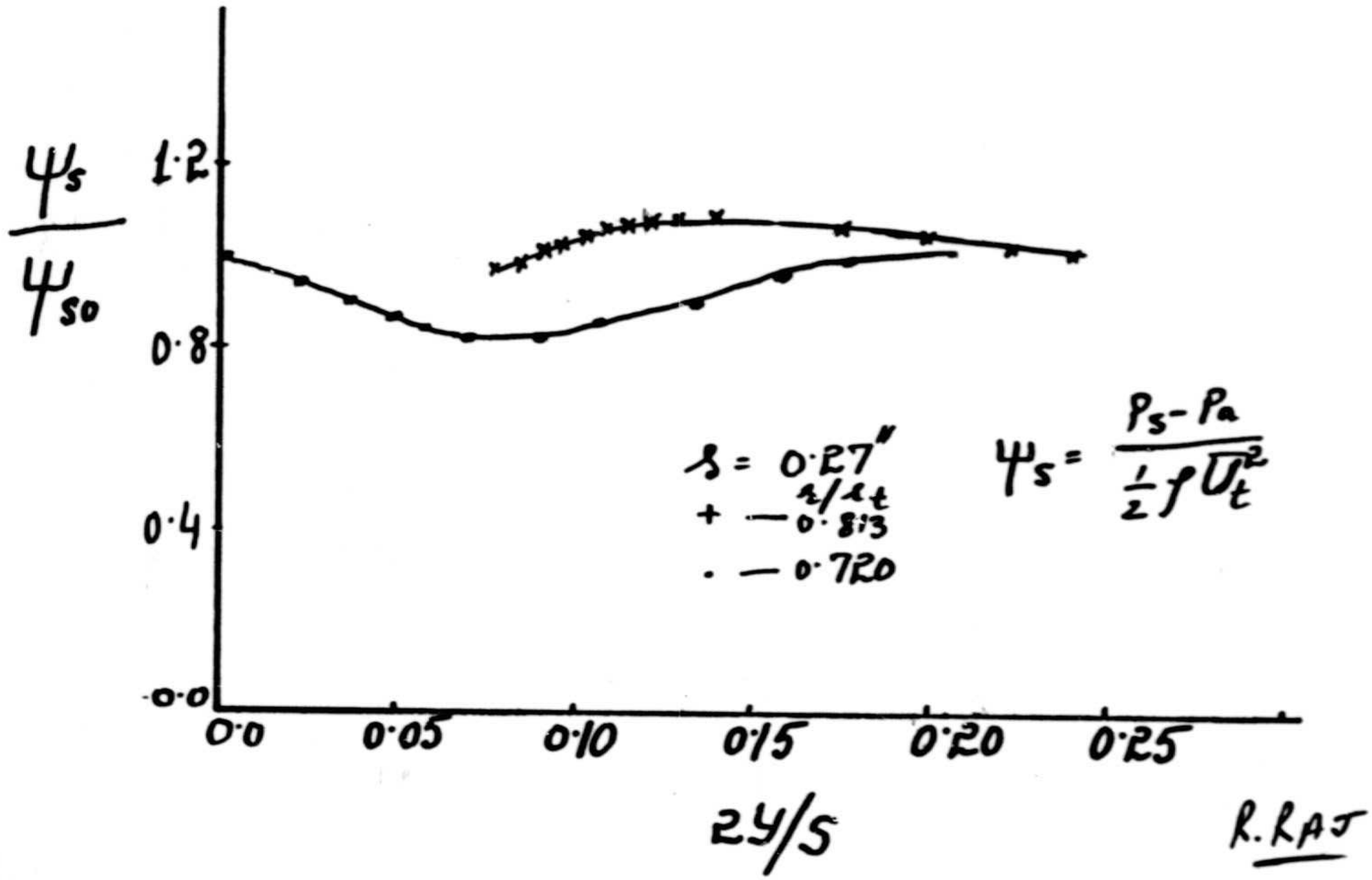

Fig. 2 Distribution of Static Pressure Coefficient Across the Wake, s/c = 0.045, 12 Blade Rotor at AFRF Facility, Zero Degree Incidence.

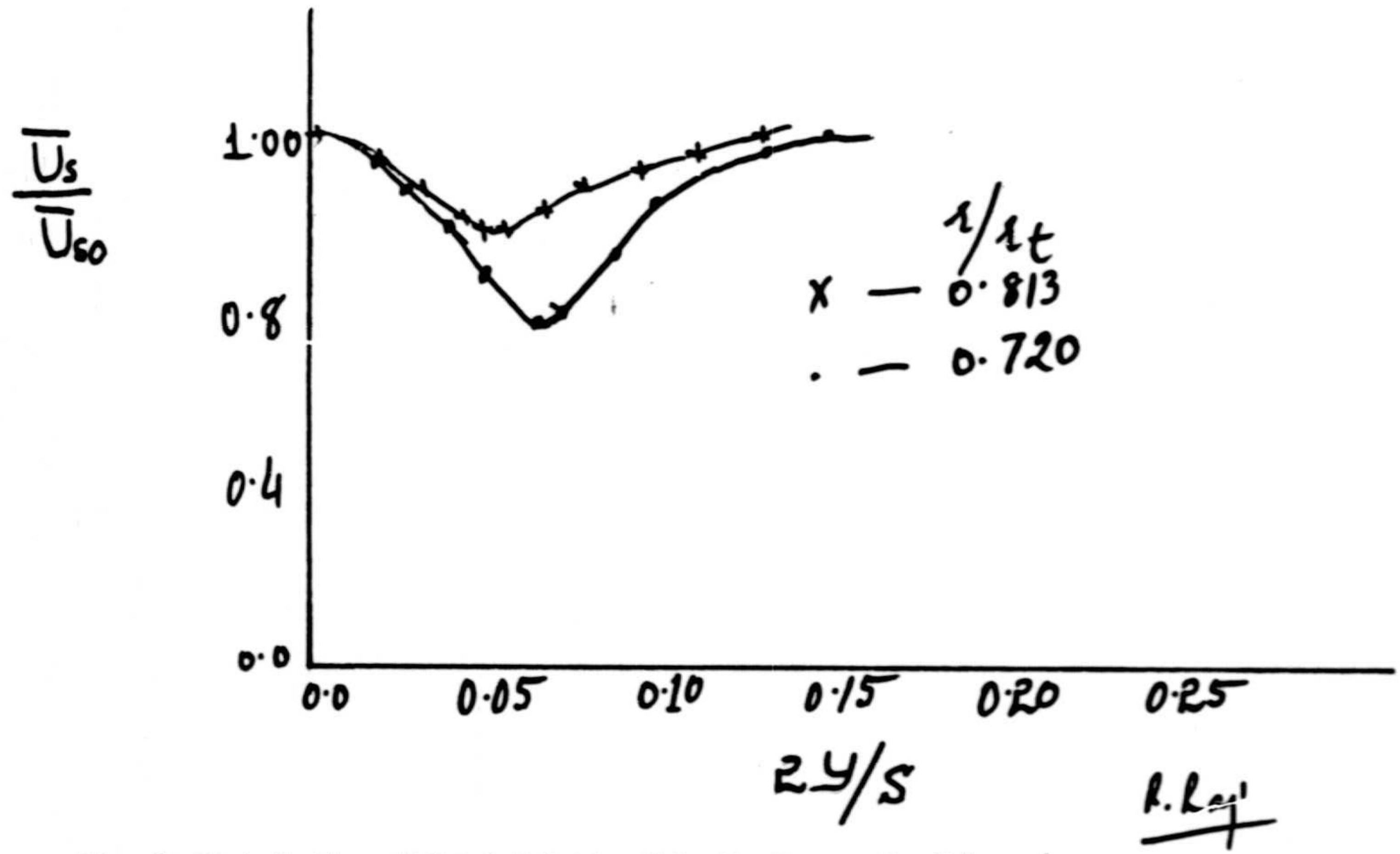

Fig. 3 Distribution of Total Relative Velocity Across the Wake, s/c = 0.045, 12 Bladed Rotor at AFRF Facility, Zero Degree Incidence.

F 3

DECAY OF WAKE DEFECT AT ℄

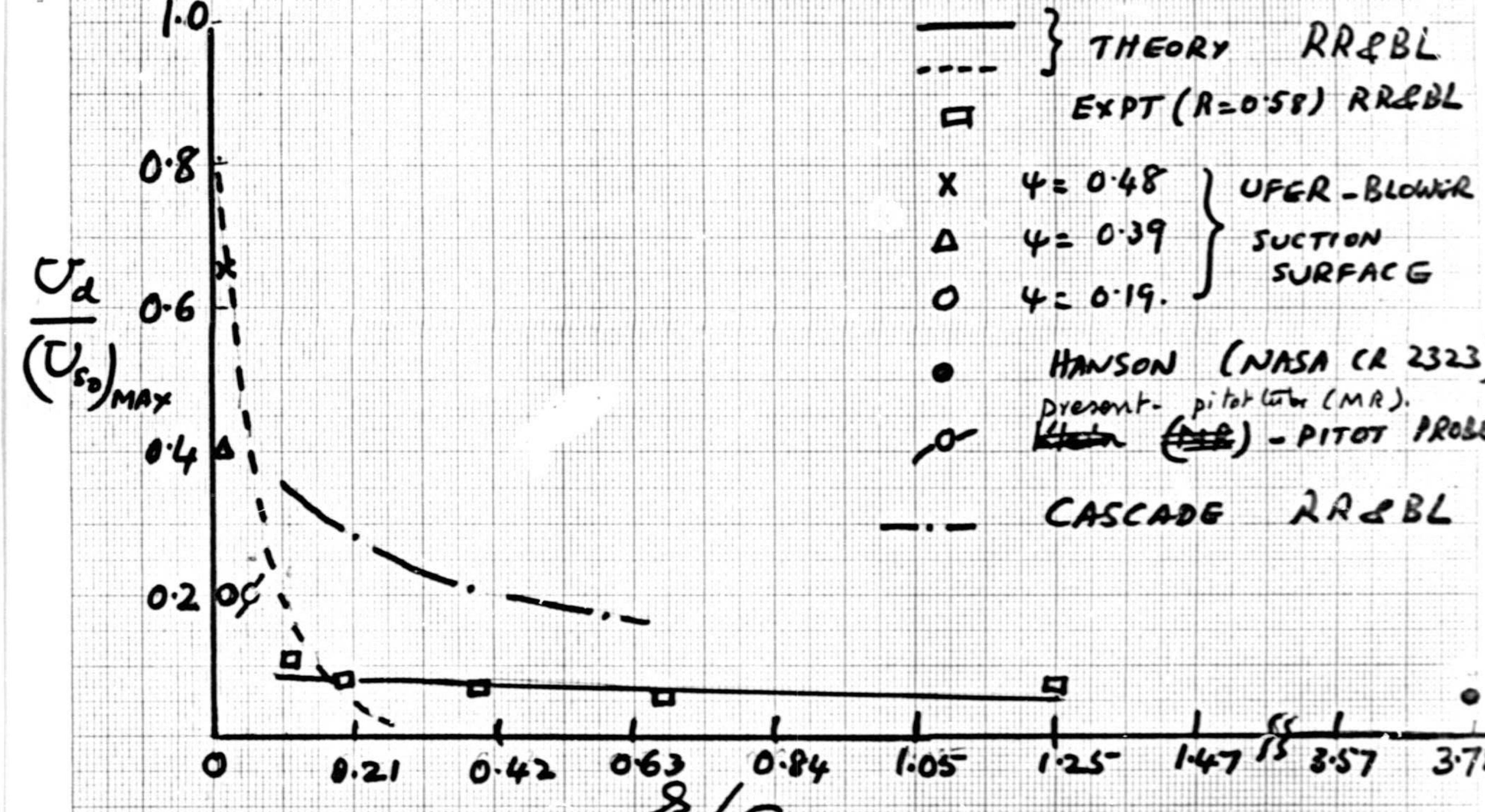

Fig. 4 Decay of Wake Defect at Centerline - Data From PSU, Hanson, Ufer.