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Improved Measurement of the Dynamic Loads Acting on Rotating Parachutes

Z. Shpund* and D. Levin†
Technion Foundation for Research and Development, Haifa 32000, Israel

An experimental apparatus for measuring the steady and nonsteady aerodynamic loads acting on parachutes and decelerators has been designed and built in the Wind Tunnel Laboratory at Technion. This apparatus was installed in the subsonic wind tunnel. Calibration tests were carried out with both deadweights and a rigid body simulating the flow around a rotating parachute. Good agreement was obtained between the results of these tests and previously recorded data. The experiments with parachutes included both static and rotating cases of a cross-type parachute with a W/L of 0.333. The measurements in the static case included all six force and moment components. In the rotating case, five load components were measured plus roll damping and roll transfer capability. The results prove the ability of the modified system in accurately measuring the aerodynamic loads without interrupting the flowfield of the parachute, as well as the versatility of the apparatus in obtaining dynamic data previously unobtainable in wind-tunnel measurements.

Nomenclature

C_f = friction coefficient
C_M = pitching moment coefficient
C_N = normal force coefficient
C_R = rolling moment coefficient
C_X = axial force coefficient
C_{ℓ_p} = roll damping coefficient
d = diameter
I = moment of inertia
L = length
p = spin rate
v = freestream velocity
α = angle of attack

Introduction

THE use of parachutes in aerodynamic planning has gained increased attention in recent years, especially for smart projectiles requiring accurate performance during the descent phase of the flight. These requirements for accuracy raise the need of enhanced wind-tunnel experimentation with full-size and scaled-down parachute models. However, wind-tunnel testing has been lagging in its role of furnishing experimental data because of its traditional shortcomings in simulating the full-scale aerodynamics using small-scale models, combined with its inability to measure accurately all of the desired load components without disturbing the flowfield around the nonrigid models.

Drag measurements were easily obtained. However, this was scarcely enough for a complete aerodynamic evaluation when large angles of attack and sideslip became involved in the cases where the stability and maneuverability of the parachute were to be measured.

An early work by Niccum et al.[1] established a method using a double support to enable mutual measurement of drag and stability. However, their work suffered from several disadvantages. The support was longitudinally rigid and the normal and drag force measuring elements were crude, thus affecting the accuracy and relevancy of the measured data. Bracing wires were installed in front of the parachute and the system was limited to static tests only. A later version of the dual support was introduced by Doherr.[2] In this system, the use of two sting balances, one with a rigid connection to the parachute and one with a slip-ring connection, provided an accurate measurement of static parachutes by allowing the parachute's model to be suspended freely between the two supporting points. However, the lack of a spinning ability in these support rigs prevented the extension of this apparatus measuring the properties of spinning parachutes.

The need for understanding the dynamic behavior necessitates the design of an apparatus that will close the gap between the existing measuring capability and the desired data. While the general approach of a dual-balance system is maintained, many modifications are introduced in the new approach. In the design of the new system, several guidelines were followed. An effort has been made to ensure frictionless rotation, minimal interference to the parachute flowfield, a well-defined mounting, and an accurate and versatile data acquisition technique.

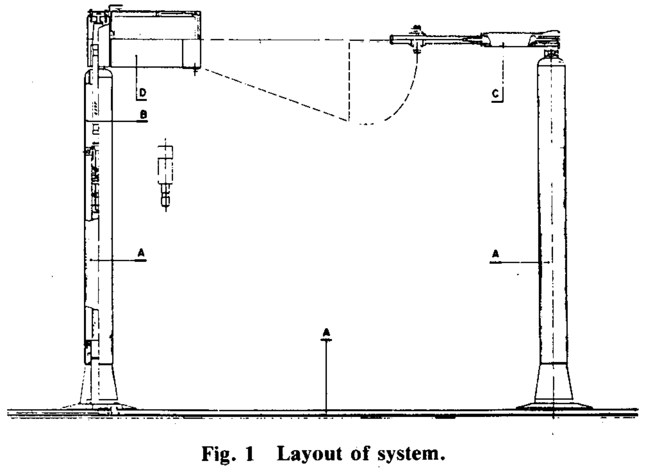

Fig. 1 Layout of system.

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*Research Engineer, Wind Tunnel Laboratory, Aeronautical Research Center.

†Head, Wind Tunnel Laboratory, Aeronautical Research Center; currently, Senior Lecturer, Department of Aerospace Engineering, Technion—Israel Institute of Technology, Haifa 32000, Israel. Member AIAA.

Description of Apparatus

The layout of the system is presented in Fig. 1. The main frame is the holder (A), which includes the dual-balance arrangement (B,C) and the rotation mechanism (D). The system can hoist parachutes of varying length. The versatility of this system is demonstrated in its ability to use any standard 16 mm balance from the wind-tunnel laboratory inventory as its main balance. The secondary balance is a miniature four-component one and is attached through a ball bushing to the parachute; see Fig. 2. This attachment ensures free longitudinal motion, without interfering with the drag measurement, and prevents rocking and noisy output during rotation and the change in the lateral forces. This last quality is of high importance when dealing with asymmetric rotating parachutes and is thus superior to the slip-ring arrangement described in Ref. 2.

The rotating mechanism (Fig. 3) is an essential constituent of the new system. It enables variation in the controlled friction, from frictionless rotation of the forebody (simulating the payload) to any desired rolling moment. Through the use of a pneumatically controlled clutch, a controlled dynamic friction moment is applied and different steady states of the rotational velocity can be obtained. Thus, aside from the five force and moment components, the amount of transferable moment from the parachute to the payload can be measured, as well as the damping in roll, as will be described later.

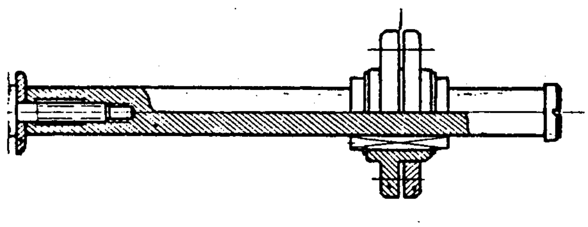

Fig. 2 Ball bushing arrangement.

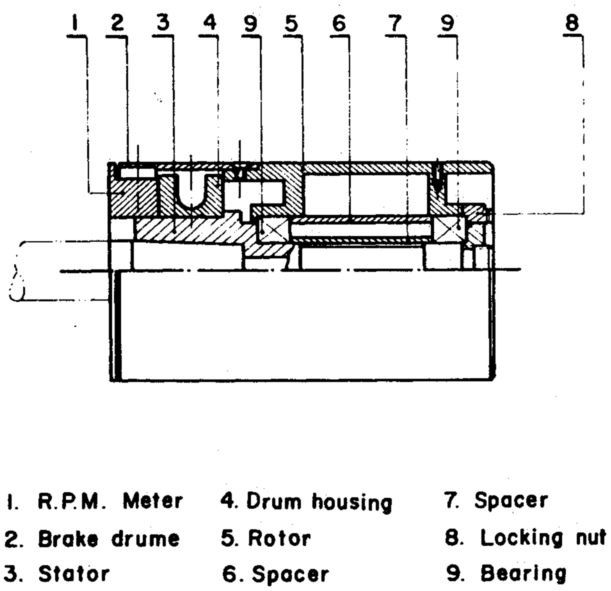

Fig. 3 Rotating mechanism.

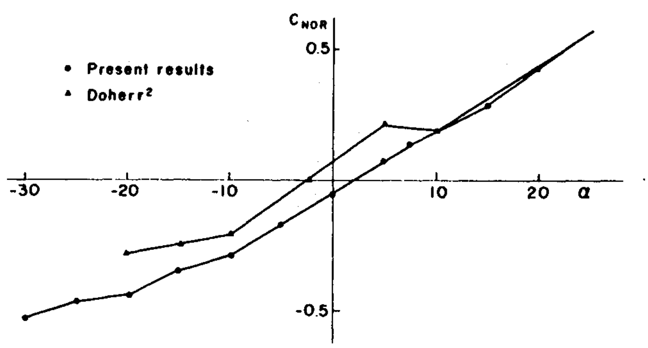

Fig. 4 Normal force coefficient vs angle of attack.

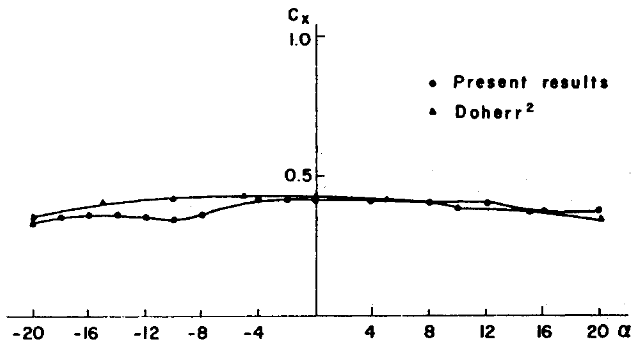

Fig. 5 Axial force coefficient vs angle of attack.

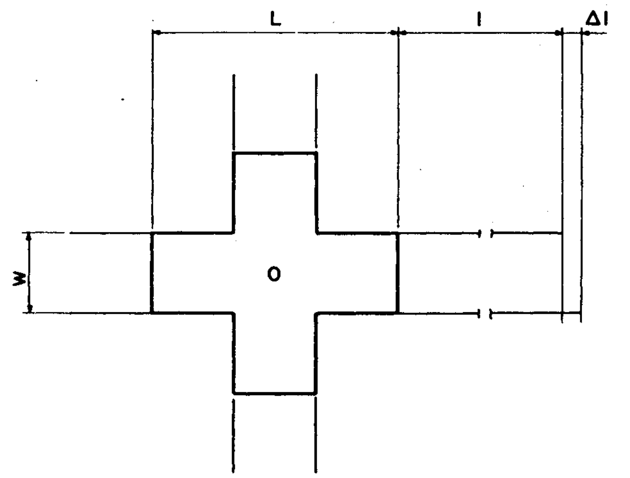

Fig. 6 Cross-type parachute.

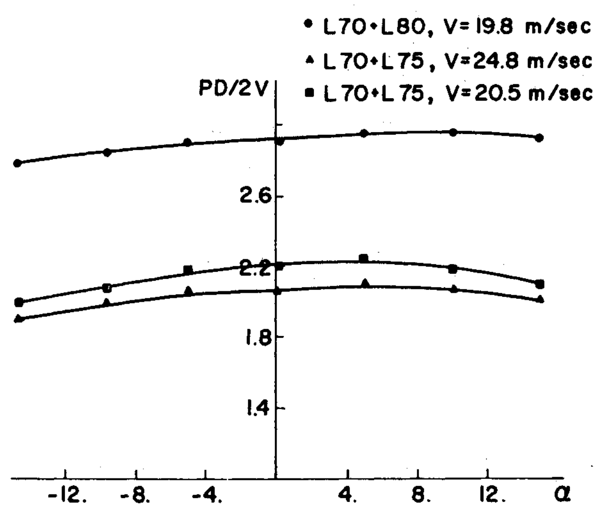

Fig. 7 Spin rate vs angle of attack.

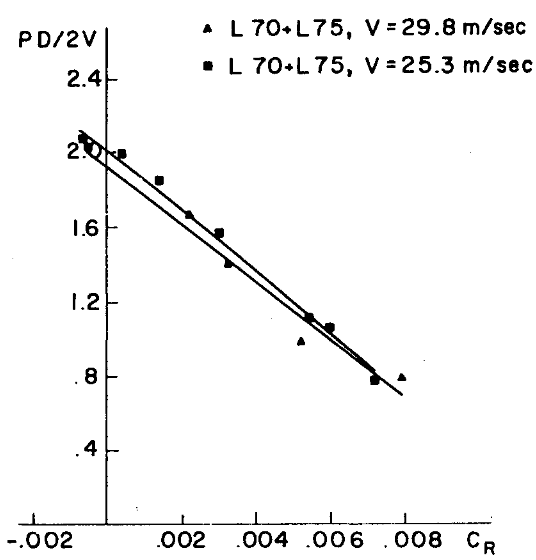

Fig. 8 Spin rate vs measured roll coefficient.

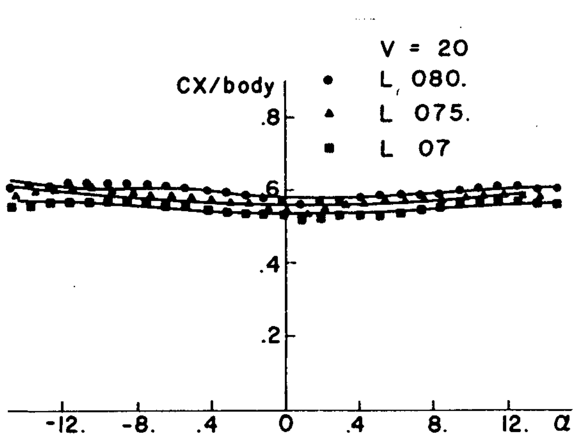

Fig. 9 Axial force coefficient vs angle of attack.

Calibration Procedure

The initial calibration of the rig was carried out by deadweight testing. This calibration postulated the method of data acquisition and reduction. A metal sleeve connected the two balances, and weights were applied in different locations along the sleeve. The accuracy of the reconstruction of the weights was better than 1% and similar results were obtained for the positioning of the weights.

In the next stage, the aerodynamic coefficients of a rigid body were measured. The rigid body was chosen after the work of Doherr.[2] The test results are presented in Figs. 4 and 5. The slight differences between the present results and those of Ref. 2 are attributed to the presence of a forebody and to the difference in the surface roughness. The model of Ref. 2 was smooth, while the model tested in the calibration tests of the new apparatus was made out of foamed polyurethane. This last effect has been further investigated and verified in another experiment by the authors.

Dynamic and Static Tests

The full scope of the new system was demonstrated by the static and dynamic tests that were carried out with a cross-type parachute, the geometry of which is presented in Fig. 6. This cross-type parachute ($L=50$ cm, $W/L=⅓$) was usually used as a static decelerator and was not designed for spin. It was chosen, however, for the current testing, because of the ease with which it could be turned from static to spinning modes with only a slight change in the chord length. In the current experiments, spinning was obtained by tying different length chords to a single lobe, thus changing the parachute into a rotor with a variable deflection angle.

Parachute's Spinning Qualities

The nondimensional spin rate variation with angle of attack is presented for the basic parachute with two chord lengths ($\Delta\ell/\ell=7$ and 14%) in Fig. 7. The effect of the freestream velocity change on the nondimensional spin rate is small compared to the effect caused by changing the deflection angle $\Delta\ell/\ell=7$ and 14%. It is obvious that, in the region of ± 15 deg, the angle of attack has but a second-order influence on the spin rate.

The method of evaluating the aerodynamic coefficient of the parachute in the roll plane is based on the assumption that the differential equation governing the roll rate increase of the parachute/payload configuration is linear, as

$$I_{\dot p} = q\cdot C_R - q\left(\frac{pd}{2v}\right)\cdot C_{\ell_p} - qC_f \qquad (1)$$

where I is the moment of inertia, $\dot p$ the spin rate derivative, q the dynamic pressure, and C_R, C_ℓ, and C_f the roll moment,

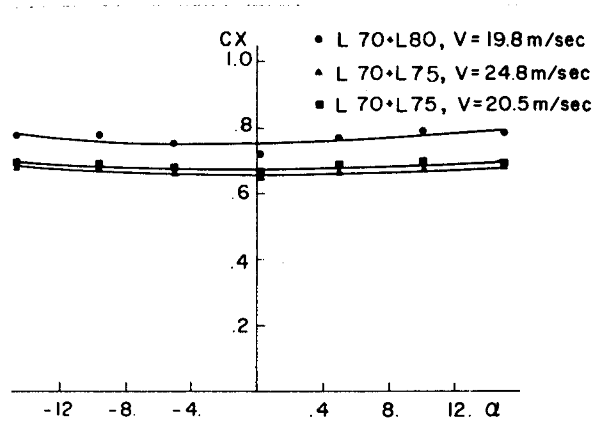

Fig. 10 Axial force coefficient vs angle of attack.

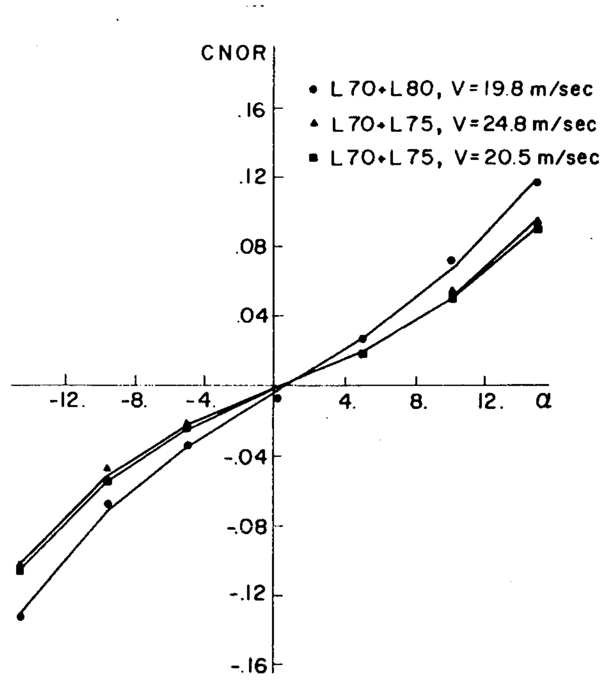

Fig. 11 Normal force coefficient vs angle of attack.

damping in roll, and friction coefficients, respectively. It can be shown that if the nondimensional roll rate is drawn vs the measured roll coefficient for different steady roll rates, as presented in Fig. 8, the slope of the curve represents the damping in roll C_{ℓ_p} and the fictitious point where the curve crosses the measured roll coefficient axis represents the linear combination of C_R and C_f. When the same procedure is carried out with various freestream velocities, a distinction between C_R and C_f is achieved. The different steady-state roll rates are obtained by applying air brakes with controlled friction. The air brakes are installed in the forebody as described in Fig. 3. It must be stressed that, in order to perform the above-mentioned measurement, there is no need to obtain specific roll rates, just various steady roll check points.

Drag Measurement

It is interesting to observe the drag results of a parachute used essentially as a decelerating device. In the nonrotating

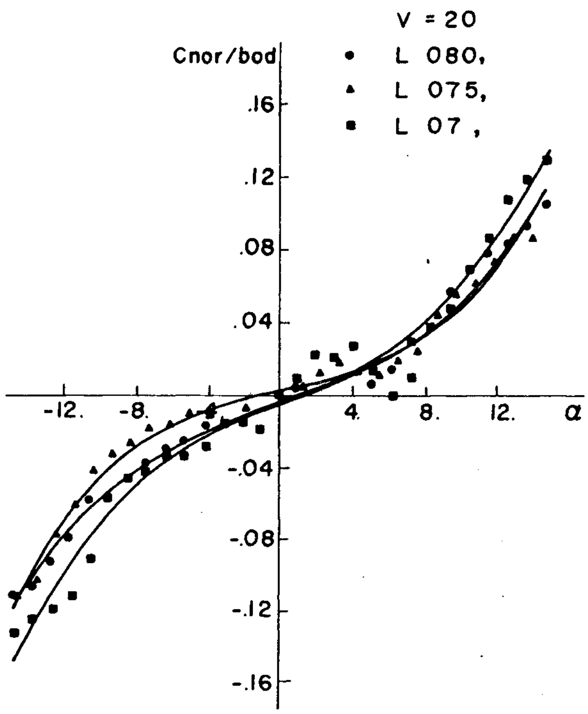

Fig. 12 Normal force coefficient vs angle of attack.

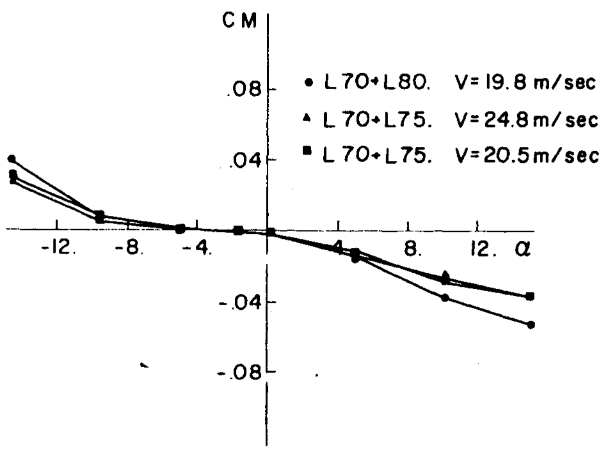

Fig. 13 Pitching moment coefficient vs angle of attack.

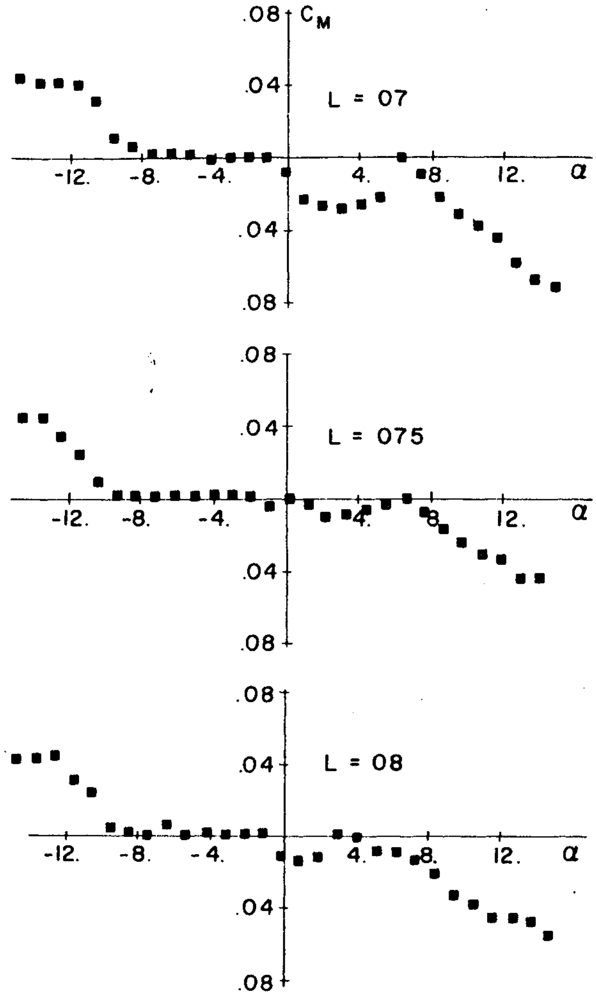

Fig. 14 Pitching moment coefficient vs angle of attack.

cases presented in Fig. 9, the measured drag coefficient is displayed vs the angle of attack, with different parachute chord lengths as a variable. An additional $\Delta\ell$ of 7 and 14% leads to a respective increase of 5 and 10% in the axial force. As shown in Fig. 10, the effect of the spin, however, is more significant and, for staging ratios of 7 and 14%, the drag increase is 25 and 45% compared to the nonspinning parachute. The effect of a change in the freestream velocity on the axial force coefficient of the parachute is negligible.

Stability Parameters

The model used to describe the parachute payload configuration assumes that the configuration behaves aerodynamically as a rigid body having nonlinear aerodynamic coefficients. In order to evaluate these coefficients, it is important to observe the variation of the normal force and pitching moment with the angle of attack. As expected,[1] a cross-type parachute produces a normal force coefficient that behaves very much like a third-order curve with α; see Fig. 11. The spin has only a small effect on the normal force behavior (Fig. 12). The moment curve (Fig. 13) shows a zero slope when α is close to zero, a characteristic that usually causes the parachute to develop a coning motion with a tip trim angle of 6 deg, as indicated in Fig. 14.

The effect of the spin on the coning tendency can be evaluated from the results presented in Fig. 14. There is an improvement in the pitching moment coefficient slope and it is negative in the region of zero angle of attack. The additional axial force acts in a stabilizing manner.

The apparatus' ability to apply controlled friction, as demonstrated in the measurement of the roll coefficients, can be used to obtain measurements of the maximal transferable torque. In any desired combination of freestream velocity and angle of attack, friction is raised until the maximal transferable torque is reached, followed immediately by a self-entwining of the chords that causes the canopy to choke.

Conclusions

An experimental study was conducted on a cross-type parachute with $W/L = 0.33$. A good agreement exists between the results of the current study and those of former experiments. The new measuring system provides the static and dynamic coefficients needed to specify the behavior during the flight of any given parachute configuration, thus improving the design and simulation capabilities available to the aerodynamicist.

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[2]Doherr, K.-F., and Schmerwitz, D., "Measurement for Rigid Parachute Models," Royal Aeronautical Society Symposium on Parachutes and Related Technologies, London, Sept. 1971.