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STATIC STRESS MEASUREMENTS ON A HIGHLY-SKEWED PROPELLER BLADE

by

Robert J. Boswell

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DEPARTMENT OF HYDROMECHANICS
RESEARCH AND DEVELOPMENT REPORT

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NOTATION

C	Camber ordinate of blade section
C_0	Maximum camber of blade section
c	Section chord length
D	Propeller diameter
P	Blade section pitch
t	Half-thickness ordinate of blade section
t_0	Maximum thickness of blade section
x	Section radius/propeller radius
y	Fraction of chord measured from leading edge
θ_s	Projected skew angle of blade section
σ_P	Absolute maximum principal stress
σ_r	Radial stress
σ_θ	Tangential stress
ϕ	Angle defining direction of principal stress, measured from radial direction positive towards trailing edge.

ABSTRACT

Static stresses were measured on a highly skewed marine propeller blade using a specially constructed pressure chamber which allowed the blade to be loaded under air pressure. The measured stress distribution was radically different from those previously measured on unskewed blades. The highest stresses occurred in a relatively narrow band extending from near the trailing edge at the blade root to near the leading edge at 90-percent radius. For a uniform pressure loading of 1.0 psi, the maximum measured principal stress was 2200 psi in compression and 1800 psi in tension. The maximum radial stress calculated by beam theory for the equivalent unskewed propeller was 910 psi both in tension and compression.

ADMINISTRATIVE INFORMATION

This work was performed under the house, independent research program of the Naval Ship Research and Development Center and funded under Subproject ZR011.01.01, Local Work Unit 526-214.

INTRODUCTION

Skewed propellers are of interest for reducing propeller-induced vibration.[1–5] However, no experimental data are available on the effect of high skew on the blade stress level. An excellent review of the literature on propeller stress is presented by McCarthy and Brock.[6]

The present study was undertaken to provide experimental data for assessing the effect of skew on blade static stresses and evaluating the adequacy of beam and or shell theories for the prediction of static stress levels in highly skewed propellers. Strain measurements were made on a highly skewed model propeller blade subjected to uniform air pressure loading using the technique developed by McCarthy and Brock.[6]

PROCEDURE

Laboratory strain measurements were conducted on a highly skewed aluminum model propeller blade. The propeller was identical to NSRDC Propeller 4143, described in Reference 7, except that the propeller tested in the present study had only one blade. Figure 1 is a drawing of the propeller and Table 1 presents its geometric characteristics.

A pressure chamber was constructed to fit around the blade to allow loading under uniform air pressure. This technique was developed by McCarthy and Brock.[6] The pressure

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[1] References are listed on page 8.

TABLE 1

Geometry of Propeller 4388

Number of Blades	1
Expanded Area Ratio	0.202
Mean Width Ratio	0.397
Blade Thickness Fraction	0.040
Section Meanline	NACA $a = 0.8$
Section Thickness	NACA 66, NSRDC modified nose and tail
Diameter	12.0 Inches

x	c/D	t_0/D	C_0/c	P/D	θ_s Degrees
0.20	0.3200	0.0329	0.0369	0.925	0
0.30	0.3635	0.0282	0.0382	0.932	15.0
0.40	0.4048	0.0239	0.0388	0.954	30.0
0.50	0.4392	0.0198	0.0362	0.991	45.0
0.60	0.4610	0.0160	0.0345	1.032	60.0
0.70	0.4622	0.0125	0.0331	1.071	75.0
0.80	0.4347	0.0091	0.0316	1.120	90.0
0.90	0.3613	0.0060	0.0289	1.181	105.0
0.95	0.2775	0.0045	0.0273	1.210	112.5
1.00	–	–	0.0256	1.240	120.0

y	t/t_0	c/C_0
0	0	0
0.005	0.0665	0.0423
0.0075	0.0812	0.0595
0.0125	0.1044	0.0907
0.025	0.1466	0.1586
0.05	0.2066	0.2712
0.075	0.2525	0.3657
0.1	0.2907	0.4482
0.15	0.3521	0.5869
0.2	0.4000	0.6993
0.25	0.4363	0.7905
0.3	0.4637	0.8635
0.35	0.4832	0.9202
0.4	0.4952	0.9615
0.45	0.5	0.9881
0.5	0.4962	1.0
0.55	0.4846	0.9971
0.6	0.4653	0.9786
0.65	0.4383	0.9434
0.7	0.4035	0.8892
0.75	0.3612	0.8121
0.8	0.3110	0.7027
0.85	0.2532	0.5425
0.9	0.1877	0.3586
0.95	0.1143	0.1713
0.975	0.0748	0.0823
1.0	0.0333	0

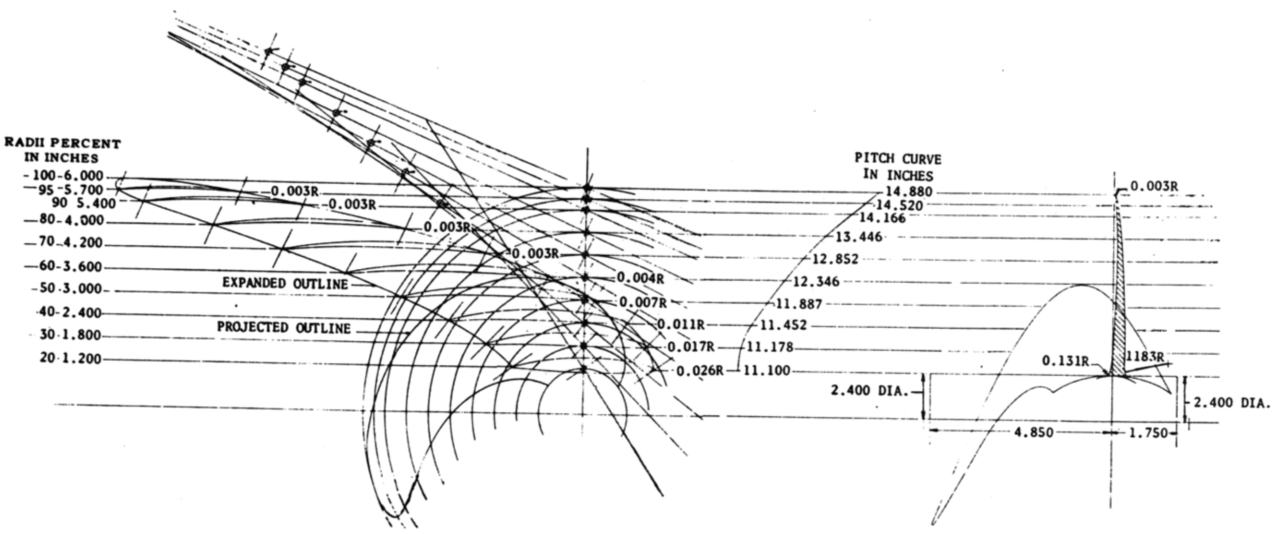

Figure 1 – NSRDC Propeller 4388

chamber was made from a wooden block with a cutout conforming to the projected blade outline and the propeller hub outline (Figures 2 and 3). The blade outline cutout was oversized to allow approximately 0.010-in. clearance between the block and the edge of the propeller blade. The top and bottom of the block-propeller assembly were fitted with gasketed 3/8-in.-thick steel plates, and the entire rig was held together by vertical bolts between the top and bottom plates. A large bolt was also fitted through the hub and dowel pins provided between the hub and plates to prevent rigid body rotation of the propeller blade and consequent contact with the wooden blocks during pressure loading.

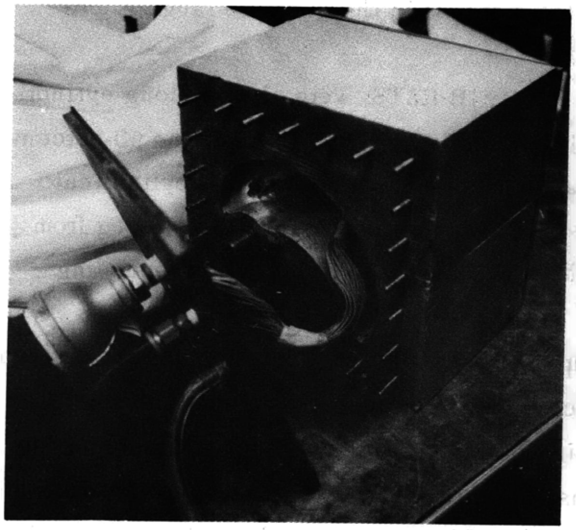

Figure 2 – Test Rig

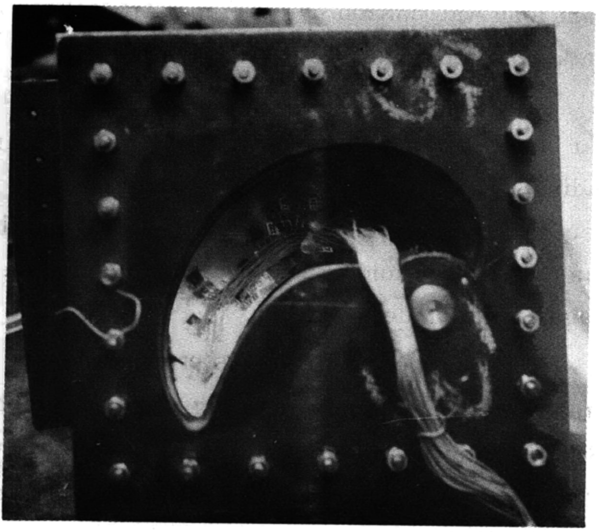

Figure 3 – Underside of Test Rig

The volume bounded by the blade, propeller hub, wooden blocks, and top plate comprised the pressure chamber. The air pressure was applied to the blade back in order to prevent contact with the block due to blade deflection under load. The top plate was provided with three holes: for air supply, a pressure gage, and a stuffing tube for exit of strain gage wires attached to the blade back. The bottom plate had a cutout conforming to the projected blade outline, from which exited the strain gage wires attached to the blade face. This opening also provided access for inspection of blade-block clearances during pressure loading. Clearances were monitored both visually and by use of feeler gages during all tests. Local contact due to large blade deflection was noticed in some of the tests and clearances were subsequently increased locally by removing wood in these areas.

To prevent excessive air leakage from the pressure chamber through the gap between the blade edge and the wooden blocks, a 1/16-in.-diameter rubber 0-ring was laid along this gap around the blade outline except in the immediate vicinity of the tip. To hold the 0-ring in place, a soft putty (plastilene) was smeared over it, forming a fillet between the edge of the blade back and the adjacent wooden blocks. Near the blade tip, the 0-ring failed to retain sufficient seal under pressure because of the sharp curvature of the blade outline and significant blade deflection (approximately 1/16-in. at a pressure of 6 psi). Sealing near the tip was accomplished by gluing a 1/16-in.-thick rubber sheet to the blade. The rubber extended along the blade edge 1 in. on each side of the point of extreme curvature and was trimmed so that when the blade was placed in the wooden box, the flap contacted the box for 1/8 in. in the direction perpendicular to the blade. A silicone lubricant was applied to the box to minimize friction between the box and the rubber flap.

Some tests were run with a larger flap (four times as much contact with the box) to determine whether the flap carried a significant load. These tests indicated that no significant load was carried by the flap. Air leakage rates were nil in the pressure range where data were recorded.

Strain gage rosettes, Budd Metalfilm Type C12-124B-R3TS, were placed along cylindrical blade sections: five each at the 30-, 50-, and 70-percent radii and three at the 90-percent radius. The rosettes were so oriented that one gage measured strain along the cylindrical section, one gage measured radial strain, and the other gage measured strain at 45 deg from the radial direction. For every gage located on the blade face, there was a corresponding gage on the blade back.

The propeller blade was pressure loaded up to 6 psi in 0.5-psi increments. For a given pressure setting, strain gage signals were graphically recorded by high-speed 48-channel Gilmore strain gage plotters. Each pressure setting required about 2 min for the recorders to plot all strain measurements. With few exceptions, the strain versus pressure plots were linear with little scatter, and the results were repeatable. The experimental results presented in the next section are based on four repeat tests under identical conditions.

All results presented were both linear and repeatable. Stresses were calculated from the strain measurements by the usual formulas, taking values appropriate for 2014 aluminum, i.e., Poisson's ratio = 0.33 and Young's modulus = 10.6×10^6 psi.

EXPERIMENTAL RESULTS

Figure 4 presents the radial and tangential stress values, and Figures 5 and 6 respectively indicate the magnitude and direction of absolute maximum principal stress (the principal stress, either tension or compression, with the larger absolute value). The stress direction is defined by the angle from the radial direction positive towards the trailing edge. All stress magnitudes shown correspond to a uniform pressure loading of 1.0 psi applied to the blade face (pressure side). (Recall that the pressure was applied to the back of the blade, which is equivalent to a negative pressure in the terminology of Figures 4, 5, and 6.)

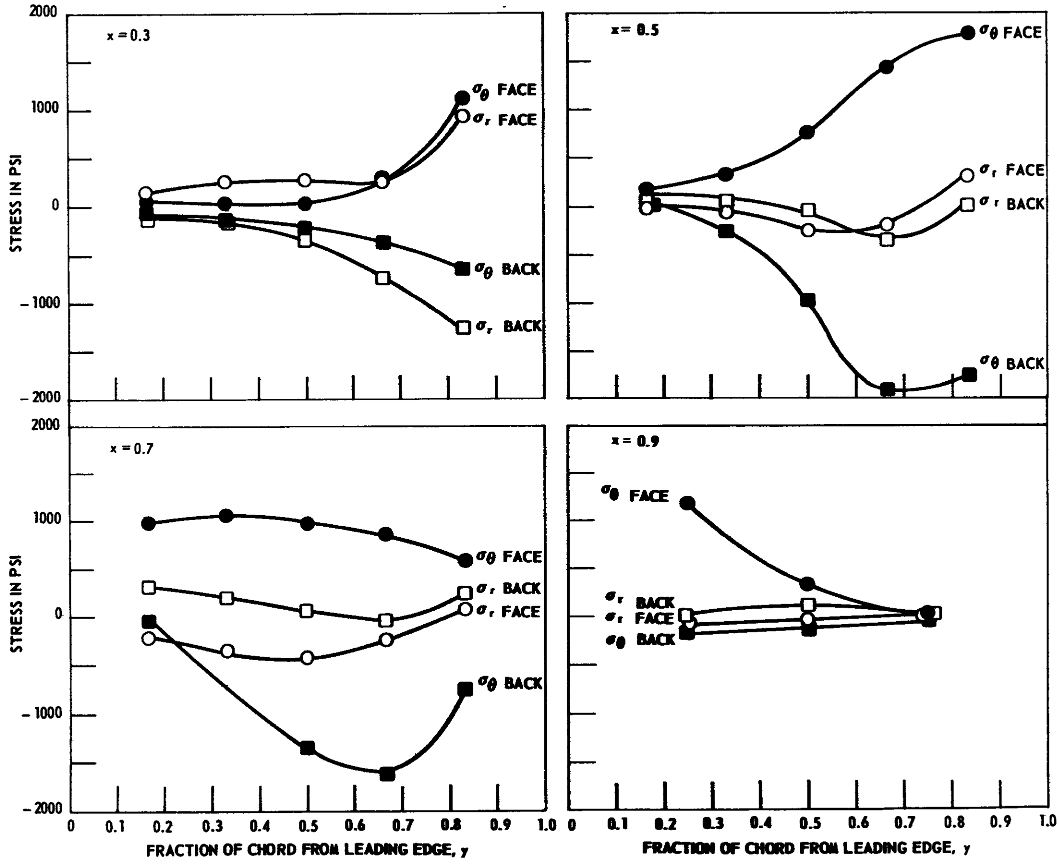

Figure 4 – Radial and Tangential Stress Distribution

Figure 4 reveals that the radial and tangential stresses are radically different from those previously measured on a similar unskewed blade under uniform loading.[6] On the unskewed blade, the radial and tangential stresses are a maximum near the points of maximum section thickness and fall off towards the blade edges, with corresponding face and back stresses being roughly equal and opposite. On the skewed blade, the chordwise stress distributions follow no general pattern; the highest stresses occur near the trailing edge at the 30-percent radius and near the leading edge at the 90-percent radius. On the unskewed blade, the radial and tangential stresses are positive (in tension) on the face and negative (in compression) on the back, and the radial stresses are generally substantially larger. On the skewed blade, the measured tangential stresses are generally much larger than the measured radial stresses, except at the 30-percent radius. Over a large portion of the skewed blade, the radial stress is negative on the face and positive on the back.

Figure 5 shows that the largest principal stresses occur in a relatively narrow region extending from near the trailing edge at the blade root to near the leading edge at the 90-percent radius (for a uniform loading of 1.0 psi). The largest measured principal stresses were 2200 psi in compression and 1800 psi in tension, both at the 50-percent radius. However,

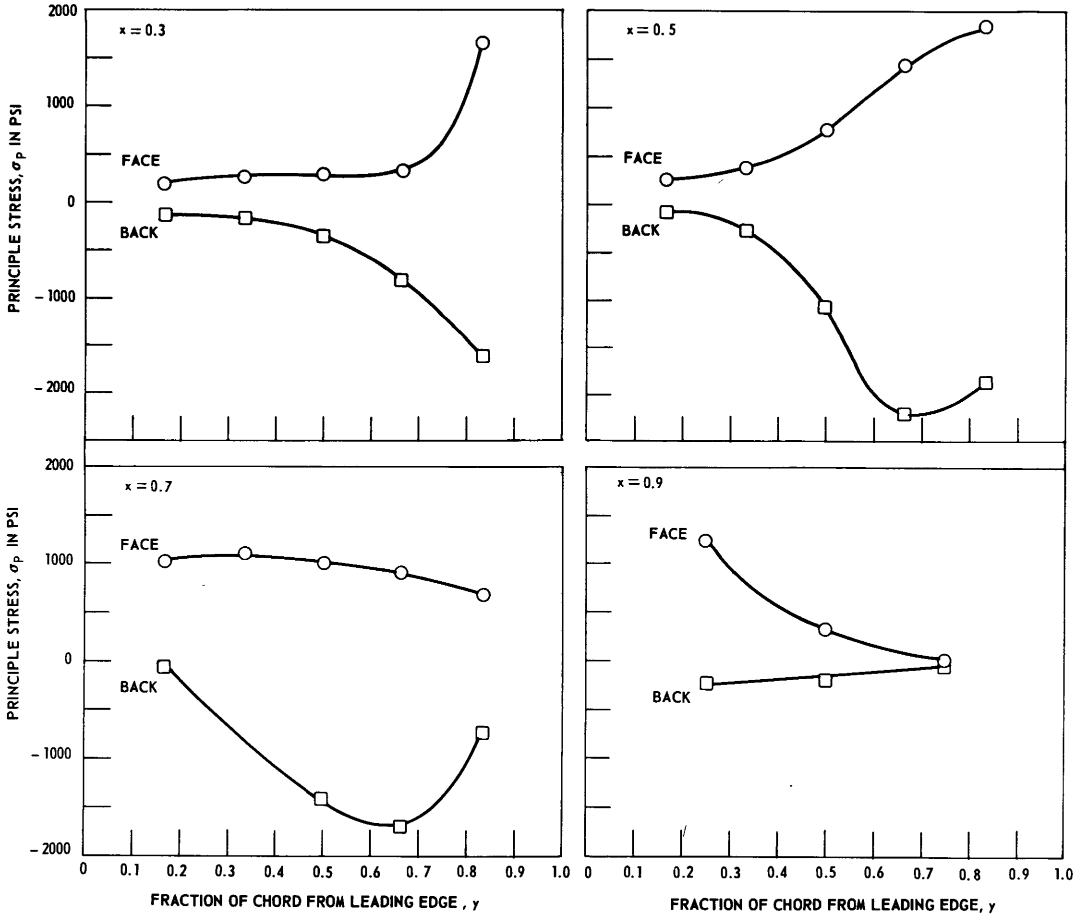

Figure 5 – Principal Stress Distribution

extrapolation of the measured stress distributions suggests that high stresses may also occur very near the trailing edge at the 30-percent radius and very near the leading edge at the 90-percent radius. Figure 6 reveals that except near the blade root, the absolute maximum principal stresses are directed nearly parallel to the blade cylindrical sections.

For all data shown, the stress levels were repeated within 50 psi for the four tests run under identical conditions. The deduced directions of the principal stresses agree to within 4 deg except near the leading edge at the 30-percent radius and near the trailing edge at the 90-percent radius where the measured stresses were very small.

No attempt has been made to calculate the stress distribution for the experimental conditions reported. However in order to obtain an indication of the increase in maximum stress due to skew, the stress was calculated for the same propeller geometry but with zero skew under uniform loading of 1 psi using the beam theory as applied by McCarthy and Brock.[6] (This method gave excellent agreement with experiment for a similar unskewed propeller.[6]) The beam theory predicted the maximum radial stress (only radial stress is calculated by this method) to be 910 psi in both tension and compression on the face and back, respectively, at the point of maximum thickness at the 20-percent radius (hub radius).

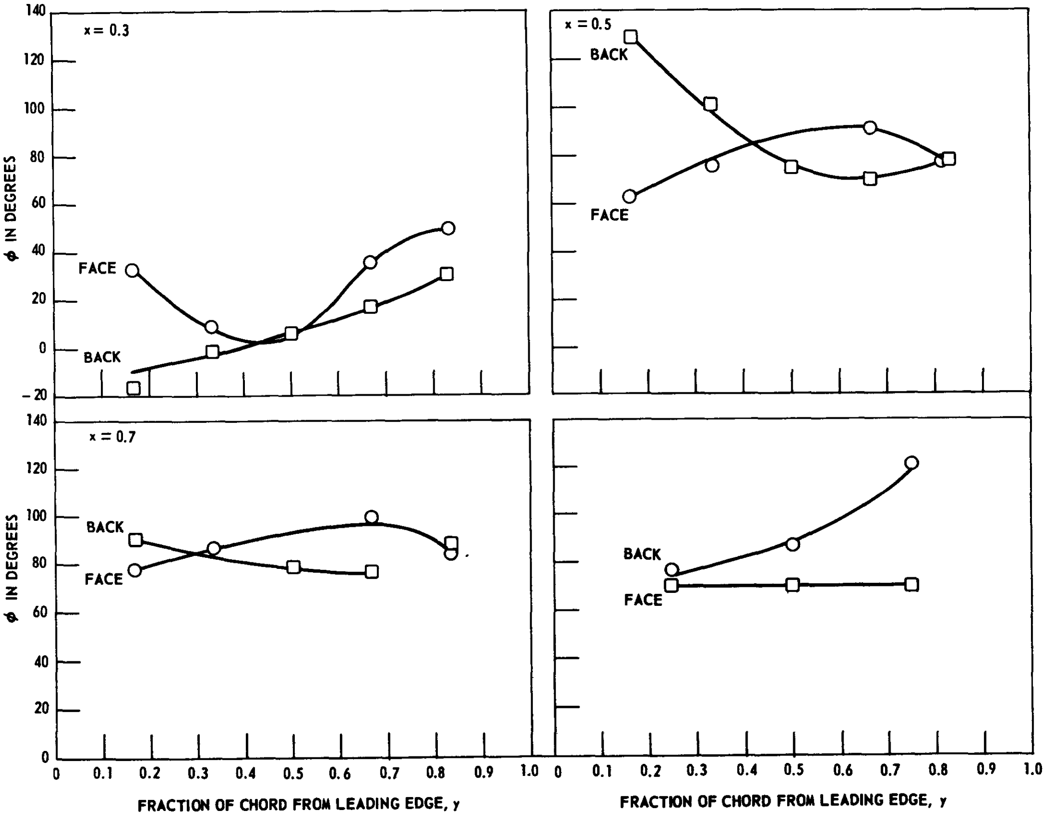

Figure 6 – Direction of Principal Stresses

SUMMARY AND CONCLUSIONS

The stress distribution was measured on a highly skewed propeller blade subjected to uniform air pressure. The test results show that:

1. The stress distribution is radically different from that previously measured on unskewed blades. The highest principal stresses occur in a relatively narrow band extending from near the trailing edge at the blade root to near the leading edge at the 90-percent radius.

2. Except near the blade root, the absolute maximum principal stresses are directed nearly parallel to the blade cylindrical sections.

3. The maximum measured principal stresses for a uniform pressure of 1.0 psi was 2200 psi in compression and 1800 psi in tension. The highest stress calculated by beam theory for the equivalent unskewed propeller at the same loading conditions was 910 psi in both tension and compression.

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13. ABSTRACT

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