NATIONAL BUREAU OF STANDARDS REPORT

5676

RESULTS OF QUESTIONNAIRE
ON
FORCES ON LANDING GEARS DUE TO GUIDANCE LIGHTS ON RUNWAYS

by

L. K. Irwin

To

Equipment Laboratory
Wright Air Development Center
Department of the Air Force

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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by

L. K. Irwin
Engineering Mechanics Section
Mechanics Division

To

Equipment Laboratory
Wright Air Development Center
Department of the Air Force

NBS Lab. No. 6.4/295-5

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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FORCES ON LANDING GEARS DUE TO GUIDANCE LIGHTS ON RUNWAYS

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1. INTRODUCTION

The construction of wider runways to accomodate the larger military jet aircraft has complicated the problems of pilot guidance by visual means at night and during inclement weather. The lights and components must provide adequate guidance for visual landings but must not be hazardous to take-off, landing and taxying operations. A proposed guidance system consisting of semi-flush lights mounted in the surfaced areas of runways is being investigated to determine some of the limiting optical and mechanical characteristics which would govern the final design configurations.

The shape of lighting equipment which projects above the runway surface not only increases the roughness of the surface but also introduces areas which may have a coefficient of friction different from that of the runway surface. After a preliminary analysis of the landing gear loads due to taxying an airplane over a proposed runway light 1 *, it was decided that the manufacturers of aircraft, including fighter, bomber, transport and cargo airplanes, should be asked for comments on the effects of the use of proposed configurations. This report reproduces the letters sent to the aircraft manufacturers and summarizes the information given in their replies.

2. QUESTIONS SENT TO THE MANUFACTURERS

Studies of several designs of flush and semi-flush light covers 1, 2, 3, 4, 5, 6 led to the formulation of a set of requirements 7 which such a system should meet. In 1956, the most promising light head appeared to be a button-type semi-flush light with a maximum height of 1.75 inches above the grade of the runway. Inquiries to the manufacturers were prepared describing the important features of this light and containing some related information. The letter and three enclosures sent to thirteen divisions and/or companies on September 11 and 12, 1956 are reproduced as Appendix A of this report. The inquiry was primarily concerned with the possibility of damage to the landing gear of aircraft when traversing the light head during

*Numbers in brackets refer to references listed at the end of this report.

normal landing and taxying operations. Eleven replies were received from the recipients of this letter.

These replies and further study indicated that the scope of the question asked of the manufacturers should have been broadened to include any detrimental response of aircraft when encountering light heads in the runway surface either singly or periodically spaced. Also an open grating steel light cover had been modified such that better performance was indicated 8 . Therefore, a second letter with four enclosures, reproduced as Appendix B, was prepared and sent on May 31 and June 3, 1957 to the eleven divisions and/or companies that had replied to the first letter. With particular reference to sketch A of enclosure 1, they were asked for comments and opinions on two questions as to the expected performance of aircraft manufactured by their respective companies. The questions were:

(1). Will the light cover cause damage during normal taxying, take-off and landing operations?

(2). With the proposed spacings of this light cover of 100 and/or 200 feet parallel to the longitudinal axis of the runway, will the running of an airplane over the light during take-off and landing operations cause excessive periodic force excitations in the airplane that cannot be damped before the airplane encounters additional protrusions?

The eleven recipients of this inquiry replied with comments and discussion.

3. RESULTS

The replies ranged from brief affirmative statements that the aircraft being manufactured would traverse the light covers without foreseeable difficulty to extensive discussions of the dangers inherent in placing protrusions on runways with supporting numerical and graphical data. Also there were suggestions on some of the problem areas that should be investigated before installing large numbers of light covers in runways. A condensed summary of the replies received is given in table 1 with the airplane manufacturers grouped as to airplane type. Each division replying was counted in tabulation of yes and no answers as many times as there were aircraft types under its cognizance. For example, Lockheed Aircraft Corporation, Burbank, California was counted twice, once for fighters and once for transports. The adverse comments on types of damage and operational difficulties that might be encountered due to the use of light heads in runways are summarized in table 1, also. Certain liberties in interpreting the comments and discussions were necessary in order to make this concise summary.

A more detailed summary of the comments, grouped by manufacturer, is given in table 2 and the attached notes. The comments and discussions in the replies were paraphrased, quoted in their entirety and/or quoted in part to build this table.

4. DISCUSSION

The manufacturers of transports, land based fighters and bombers were generally critical of increasing the roughness of runway surfaces by introducing protruding light heads. It was pointed out that while flush light heads would solve the structural problems, the problems associated with braking on a surface with a coefficient of friction different from the runway would remain unresolved. The manufacturers of cargo airplanes designed for rough field operation and carrier based aircraft did not anticipate any significant structural damage due to the light heads described in the appendices.

5. ACKNOWLEDGMENT

The cooperation of the officers and engineers of the companies listed in table 2 is gratefully acknowledged. In many replies to the two inquiries, detailed and comprehensive discussions of the problems raised by semi-flush lighting systems were included. Also, the author wishes to acknowledge the assistance of Miss W. D. Kroll in preparing most of the supplementary material that was included with the letters to the manufacturers.

For the Director

BLWilson

B. L. Wilson, Chief,
Engineering Mechanics Section,
Division of Mechanics.

Washington, D. C.
December 1957.

Table 1. Summary of Replies by Airplane Type

Type of plane manufactured	Totals of answers to question: Will planes traverse light without damage?			Totals of expected types of damage or operational difficulties due to lights installed in the runway.						
	Yes	No	Perhaps	Wheel or rim damage	Nose wheel shimmy	Effectiveness of braking system	Loss of directional control	Excitation of structure at resonance	Structural fatigue	Exceed limit load
Answers to letters dated September 11 and 12, 1956										
Fighter	2	4	-	2	1	2	1	1	-	4
Bomber	1	2	-	2	-	1	1	1	1	-
Transport or Cargo	3	2	-	-	-	3	-	2	-	1
Answers to letters dated May 31 and June 3, 1957										
Fighter	3	2	1	1	1	2	1	2	1	2
Bomber	2	1	-	-	-	-	-	2	1	1
Transport or Cargo	3	2	-	1	-	2	-	2	1	2

Table 2. Summary of Replies Grouped as to Manufacturer

Manufacturer	Replies to question: Will planes traverse 1-1/4" high lights without damage?		Will planes traverse 1/2" high lights (singly and/or equally spaced) without damage?	
	Affirmative comments*	Negative comments*	Affirmative comments*	Negative comments*
Boeing Airplane Co. Wichita, Kansas	-	a,b,c	-	a,b
Boeing Airplane Co. Seattle, Washington	A,B,C	-	B,I	-
Chance Vought Aircraft, Inc. Dallas, Texas	D	-	E,J	-
Convair Fort Worth, Texas	-	e,f,g	E,J	-
Douglas Aircraft Co. Inc. Santa Monica, California	-	a,d,h,i	-	a,d,h,i,r
Fairchild Engine & Airplane Corp. Hagerstown, Maryland	E	-	E,K	-
Lockheed Aircraft Corp. Burbank, California	-	a,d,f,j,k	L	a,b,s
Lockheed Aircraft Corp. Marietta, Georgia	E	-	E,M	d,t
North American Aviation, Inc. Columbus, Ohio	F	l,m,n	J,N	m,n,u

(Continued)

Table 2. (Continued)

Manufacturer	Replies to question: Will planes traverse 1-1/4" high lights without damage? Affirmative comments*	Negative comments*	Will planes traverse 1/2" high lights (singly and/or equally spaced) without damage? Affirmative comments*	Negative comments*
North American Aviation, Inc. Los Angeles, Calif.	G	o,p	E,J	-
Republic Aviation Corp. Farmingdale, New York	H	q	E	-

*letters indicate the appropriate comments appended to this table

Affirmative comments

A. No serious structural effects on main and outrigger gears observed during taxi tests over bumps higher than 1-3/4 inches and speed from 5 to 50 knots.

B. It is felt that for normal landings no serious structural problems would be involved for the 707, KC-135 or B-52 airplanes.

C. It is felt that the probability of having both a hard landing and critical phasing (spin-up drag load on the gear phased with the drag load due to a bump in an additive manner) is extremely remote.

D. Airplanes designed for carrier operations to land on and run over 1-3/8 inch diameter cable therefore, an obstacle as described could be negotiated without any serious difficulty during field operation.

E. Aircraft will traverse the light head without damage during normal take-off, landing and taxying operations.

F. Analysis of engineering data from drop test programs would seem to indicate that no structural damage would result.

G. For ground handling conditions (taxying) and landings on top of the light with normal operating conditions, the F-86, F-100 and F-107 can traverse the light without damage. The F-86 can traverse the light without damage during normal take-off and landing operations.

H. Our opinion is that such lighting has no serious effect and is practical insofar as airplanes manufactured by this company are concerned.

(Continued)

Table 2. (Continued)

I. The fore and aft bending response to an initial bump would be completely damped out prior to the next bump at lower ground speeds and would be essentially damped out prior to the next impact at the higher ground speeds.

J. With the proposed spacing, the shock strut and/or tires will damp out any extensive force excitations imposed before contact with the next light.

K. There should be no excitations to our airplanes that would interfere with any directional control or protrusion.

L. The modified light design (1/2 inch high) would not be expected to cause damage during normal landing and taxying operations.

M. Large, low pressure, flotation-type tires used on the C-130A serve to attenuate the gear reactions due to the 1/2 inch high light.

N. The reduction in height to 1/2 inch basically eliminated the possibility of excessive structural loads being imposed on the landing gear shock struts or wheels during normal taxying, take-off or landing operations.

Negative comments

a. The sustained, periodic excitation of the aircraft during landing and take-off will cause significant dynamic loads.

b. The continued operation of aircraft from runways with the proposed protruding lights would increase structrual fatigue problems.

c. Tire failures during taxi tests indicate that the steeper gradient and shorter dwell of the proposed light aggravates the problem.

d. Adverse affect on braking depending upon the spacing and/or different coefficients of friction of lights and runway.

e. Analysis shows that the main wheel rim loads would exceed the limit if the 1.75 inch light were hit at maximum speed with a tire slightly over-deflected at the time of contact.

(Continued)

Table 2 (Continued)

f. The effects of striking the light with one wheel of a dual-wheeled gear should be studied.

g. Light should be designed to present smooth contour (eliminate sharp flanges, bolt heads, etc.) to prevent damage to tire treads during touchdown.

h. The loads on the nose wheel could be dangerously increased by taxying over the 1.25 or 1.75 inch high bumps under adverse taxi conditions such as steering and/or main gear braking.

i. Uncertainties exist regarding the safety of the airplane during braking due to different coefficients of friction between the tire and runway surface or light which could cause damaging fore and aft forces on the gear and structure.

j. During landing impact and spin-up, the additional load that would be added to the vertical reaction due to a 1.0 inch bump would be of the order of a 10 percent increase and could produce failure in the case of an ultimate sinking speed landing.

k. The difference between the free radius and flat tire radius of some nose wheel tires is about the same as the height of the light, for example, 1.85 inches compared with 1.75 inches. If this tire were to strike the light with a moderate initial load on the tire, the tire would more than bottom and very large vertical and drag loads would result.

l. Some degree of wheel-rim damage could be incurred that would affect the ability of tubeless tires to maintain an adequate wheel-to-tire seal.

m. Runway protrusions could excite nose wheel shimmy.

n. Off-center contact of a nose wheel with a wet runway obstruction could induce a momentary directional instability configuration and result in a loss of directional control.

o. The F-100 and F-107 airplanes are not capable of tranversing the 1.75 inch high light head without damage during normal take-off and landing operations.

(Continued)

Table 2 (Concluded)

p. None of the airplanes (F-86, F-100 and F-107) are capable of traversing the light head without damage during landing when initial contact is made just in front of the protrusion.

q. For the limit sinking speed and contact between tire and light at the end of the strut stroke, the limit load could theoretically be exceeded but the probability of such an occurrence is so remote as to be considered academic.

r. An analysis of the DC-7C elastic airplane taxying over the 1/2 inch high light did not indicate high loads but cannot be taken as indicating similar response for all aircraft since smaller or larger straight wing or swept wing aircraft might respond differently.

s. For landings at near-limit sinking speeds, any increment of loading due to the light will increase somewhat the probability of reaching limit load. The use of the 1/2 inch high light may increase the probability of reaching limit load by about 50 percent.

t. The effects resulting from operation of light, high speed aircraft, equipped with small wheels at high tire pressures, may pose some problems.

u. Some concern is held for how the differences in friction between the runway and light system will affect the reliability and effectiveness of the nose gear steering, differential braking, braking and anti-skid systems.

6. REFERENCES

1. Kroll, Wilhelmina D., "Landing Gear Loads Resulting from Taxying Airplane Over a Projecting Runway Light", Progress Report 1, National Bureau of Standards Report No. 4574, March 1956.

2. Irwin, L. K., "Results of Static Loading Tests of Elfaca Gratings by Aircraft Tires", National Bureau of Standards Report No. 4086, May 1955.

3. Irwin, L. K., "Static Loading Tests of Flush-Type Runway Light Heads", National Bureau of Standards Report No. 4358, October 1955.

4. Irwin, L. K., "Static Loading Tests of A.G.A. Expendable Top Runway Light Head Assemblies with Glass Covers", National Bureau of Standards Report No. 4565, March 1956.

5. Douglas, C. A., I. Nimeroff and A. N. Hill, "Development of Optimum Runway Lights for Jet Aircraft", Interim Report No. 1, National Bureau of Standards Report No. 4741, June 1956.

6. Irwin, L. K., "Static Loading Tests of an A.G.A. Expendable Top Runway Light Head Assembly with a Glass Cover", National Bureau of Standards Report No. 4783, July 1956.

7. Anonymous, "General Requirements for Light, Flush Runway and Taxiway Marker", HQ Wright Air Development Center, WCLEE5-67A, August 1, 1956.

8. Price, J. I. and L. K. Irwin, "Static Load-Deflection Relations for 20 x 4.4 and 32 x 8.8 Aircraft Tires on an Elfaca Model C Runway Light Cover", National Bureau of Standards Report No. 5403, July 1957.

7. APPENDICES

7.1 Appendix A

A letter with three enclosures, marked for use in this report as figures 1, 2 and 3, was sent to thirteen manufacturers on September 11 and 12, 1956. The subject of this letter was "Forces on Landing Gears" and the text was as follows:

Gentlemen:

The Equipment Laboratory of Wright Air Development Center and the National Bureau of Standards are endeavouring, with the cooperation of other agencies, to devise a runway lighting system suitable for use with modern military jet aircraft and compatible with the requirements of commercial transport or light liaison type planes. New runways under construction are enough wider than previously constructed runways to require that the lights for pilot guidance be located in the paved area. The problem at hand is to devise lights and components which will not be hazardous to landing and taxying operations and yet will provide adequate light for visual landings.

A set of requirements dated August 1, 1956 has been drawn up by the Equipment Laboratory to assist with the development of adequate lights. Quoting from paragraph 3.3.3 of these requirements "Load and stress conditions. - All lights shall be designed to withstand, when properly installed, being run over by any type of aircraft, without damage to the aircraft or light, ...", it is evident that to evaluate the effect of landing and taxying all existing and projected aircraft over all feasible light head designs is not practicable. By means of analyses of certain landing gears interacting with arbitrarily chosen projections and by examination and static loading of numerous prototype lights and light heads, the types under consideration have been somewhat reduced.

The type of light head with good characteristics optically and from the view point of maintenance probably will project slightly above the runway surface. A profile of such a light is shown in enclosure 1. From the information available to us, it appears that large main gears will traverse light heads of this type without difficulty. However, the effects on nose, outrigger and tail gears when encountering obstructions of this magnitude are not

clear. Considerable difficulty has been experienced in collecting all the data required to make complete analyses of the many types of gears in use today.

Preliminary analyses, neglecting the effects of shimmy and yaw, indicate that the most important feature of the proposed light heads will be their effective height above the runway surface. Length and shape of leading edges appear to be of secondary importance. Enclosure 2 is the response curves, derived by W. Kroll of this section, for a fighter type airplane and nose wheel taxying over a 0.75 in. projection. Enclosure 3 is the response curves of this fighter nose wheel when taxying over lights of different heights. From these curves, it is seen that the landing gear and tire must be able to take an additional deflection approximately equal to the height of the light. For taxying, it is believed this condition can be met. However, for landing we do not know what the response would be. The analysis of the case of a landing on or just ahead of this projection has not been feasible with the information received to date.

In view of these considerations, we are requesting the assistance of airframe manufacturers in answering the following question: Will the aircraft manufactured by your company traverse the light head shown in enclosure 1 without damage during normal landing and taxying operations?

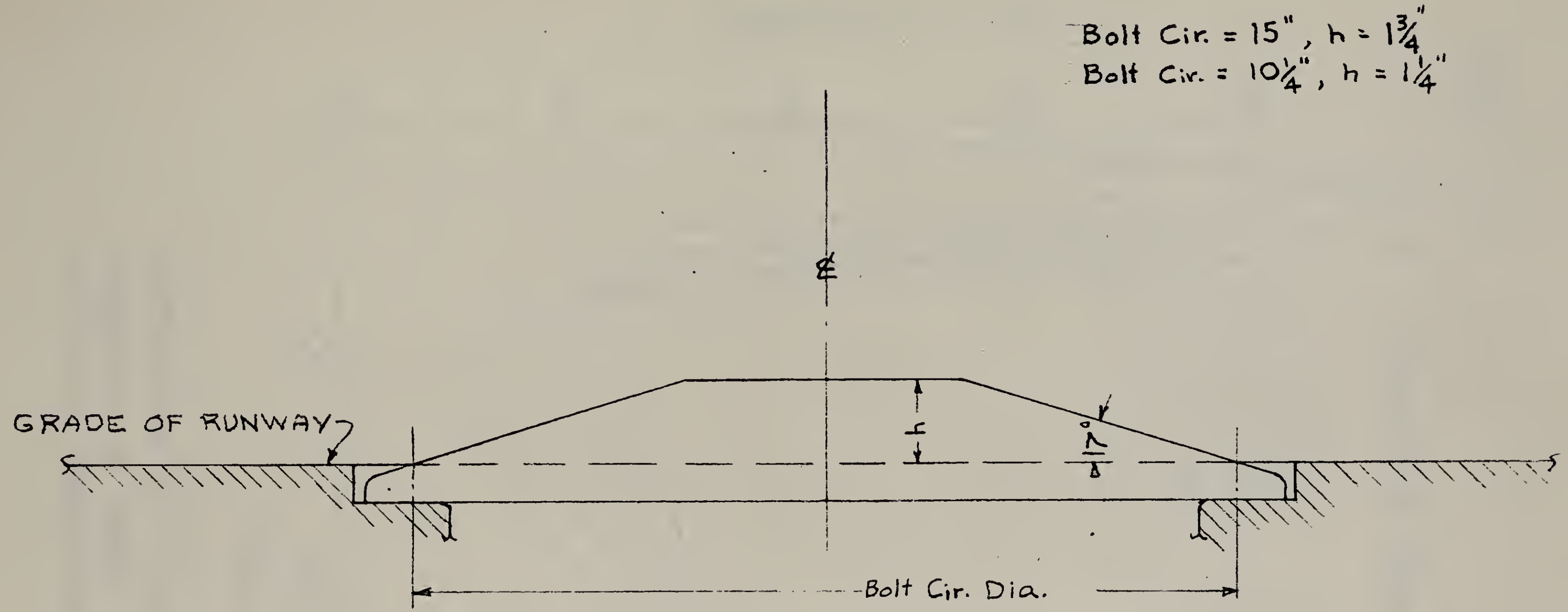
We appreciate the fact that an unqualified yes or no answer is unlikely but what we want is a considered opinion as to whether or not this type of light will be practical. I will be glad to furnish any additional information we have and to confer in person with members of your staff concerning this problem.

Very truly yours,

/s/ L. K. Irwin

L. K. Irwin,
Mechanical Engineer,
Engineering Mechanics Section.

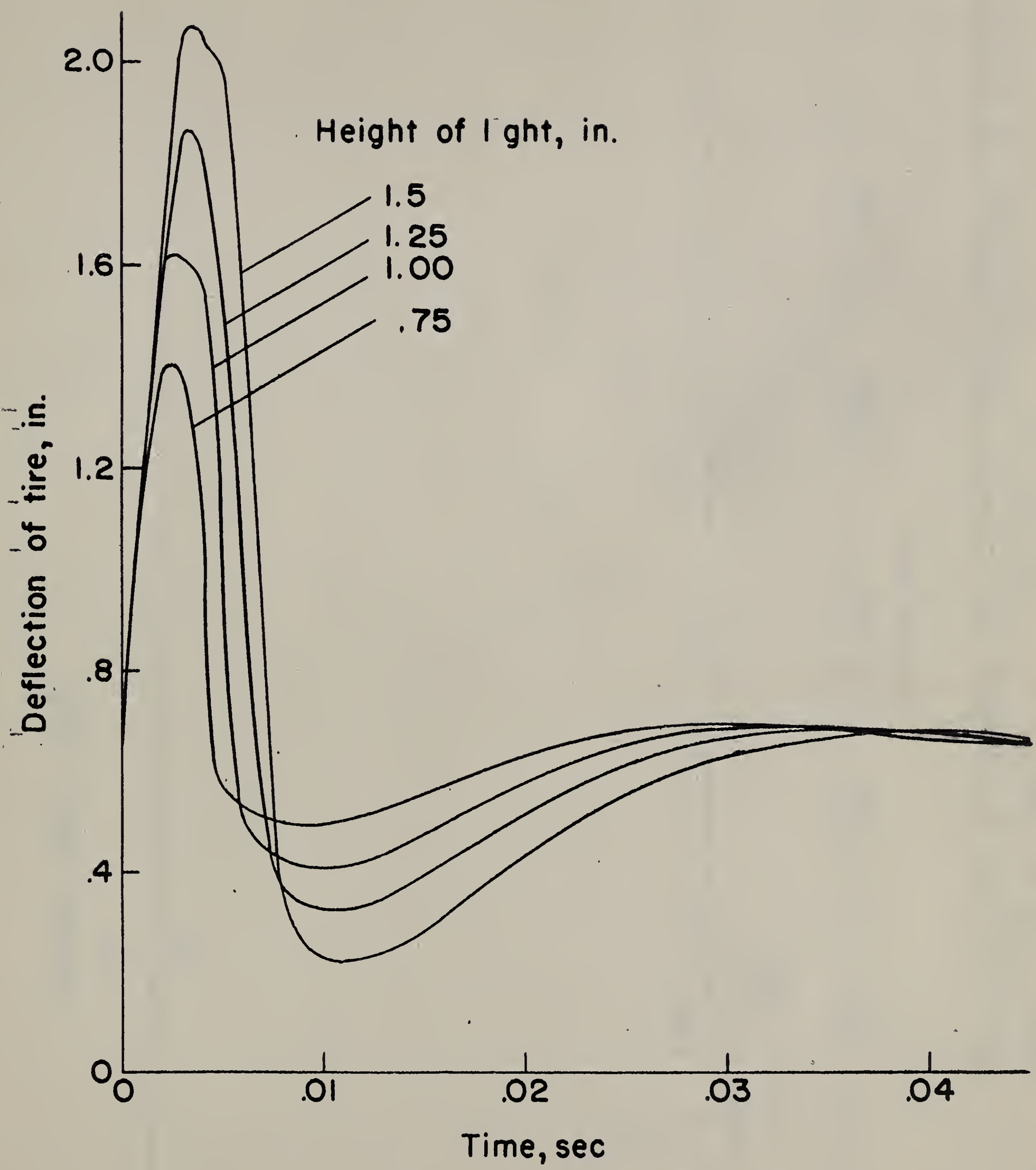
Enclosures



PROFILE OF SEMI-FLUSH LIGHT

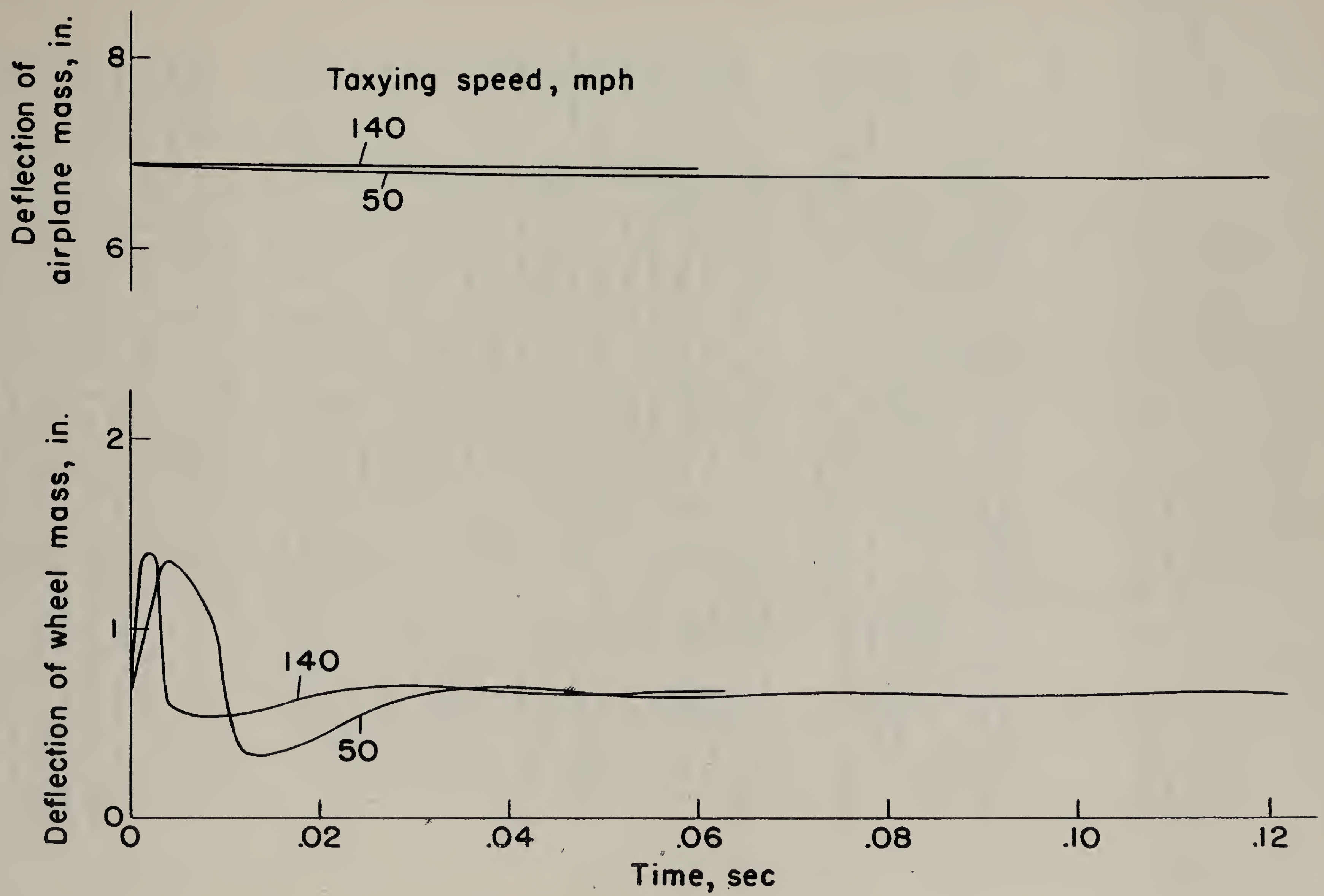
ENCLOSURE 1

Figure 1



Deflection of tire of nose wheel as F-86H airplane is taxied over trapezoid lights of different heights at 110 mph.

Figure 2



Displacement of airplane and of wheel when taxying over trapezoidal light 0.75 in. high. $W_1 = 1811$ *lb.*

Figure 3

7.2 Appendix B

A letter with four enclosures, marked for use in this report as figures 4, 5, 6 and 7, was sent to eleven manufacturers on May 31 and June 3, 1957. The subject of this letter was "Forces on Landing Gears" with reference to the previous reply. The text was as follows:

Dear Mr. -----:

Your comments in the letter referenced above were greatly appreciated and were transmitted to the Equipment Laboratory of WADC. Since our letter of September 1956, a modified version of the steel grating light cover which had been developed and used in limited numbers abroad, has been accepted by the Air Force for an experimental installation. The profile of this system parallel to the runway is shown as sketch A of enclosure 1.

In order to get an estimate of the reaction of the airplane to this shape of light, a simplified analysis was made. The airplane and its landing gear were considered to be a single degree-of-freedom system. The shock absorber was compressed the amount it would be if the airplane were taxying on a smooth runway but no additional compression or extension of the shock absorber was considered to occur as the plane taxied over the protruding light. The deflections of the tire of a fighter nose wheel and of a bomber main wheel as the planes were taxied over the light are shown in enclosures 2 and 3. For comparison, the deflection-time curve for a fighter nose wheel traversing a light head with the profile shown as sketch B of enclosure 1 is given in enclosure 4. It is felt that, in operation, the periodic vertical displacements indicated by these analyses would be attenuated by the action of the oleos. The type and extent of the data available to us at this time do not make practicable a much more accurate approach to the actual problem.

We are therefore asking again for your assistance, together with that of other airframe manufacturers, in deciding whether the use of slightly protruding (1/2 in.) light covers in the paved areas of military runways is feasible. While it is thought that the light cover shown as sketch A of enclosure 1 will not induce excessive loads in the landing gears of aircraft during normal taxying and take-off operations, the additional loads due to traversing this light cover during landing operations cannot be estimated with the information received to date. We will

appreciate your comments and opinions on the following questions concerning the expected performance of aircraft manufactured by your company when traversing light covers similar to sketch A of enclosure 1.

(1). Will the light cover cause damage during normal taxying, take-off and landing operations?

(2). With the proposed spacings of this light cover of 100 and/or 200 feet parallel to the longitudinal axis of the runway, will the running of an airplane over the light during take-off and landing operations cause excessive periodic force excitations in the airplane that cannot be damped before the airplane encounters additional protrusions?

If the experimental installation of these steel light covers is made, the effects of the protrusions on braking and steering operational aircraft will probably be studied. A limited exploratory type of investigation of the forces on landing gears traversing protruding light heads will be undertaken this calendar year at NACA, Langley Field, Va. Available equipment, however, will not permit studies of the periodic force excitations that would probably be induced in the airplane structure.

A summary of the comments and discussions received in reply to our earlier letter and this inquiry along with other related information, will be prepared for WADC. It is thought that this summary can be furnished to those manufacturers requesting a copy.

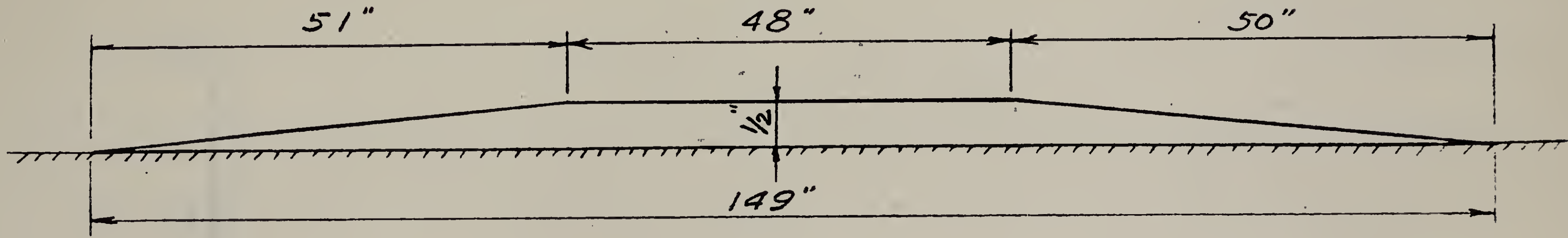
Thank you for your cooperation in this matter.

Very truly yours,

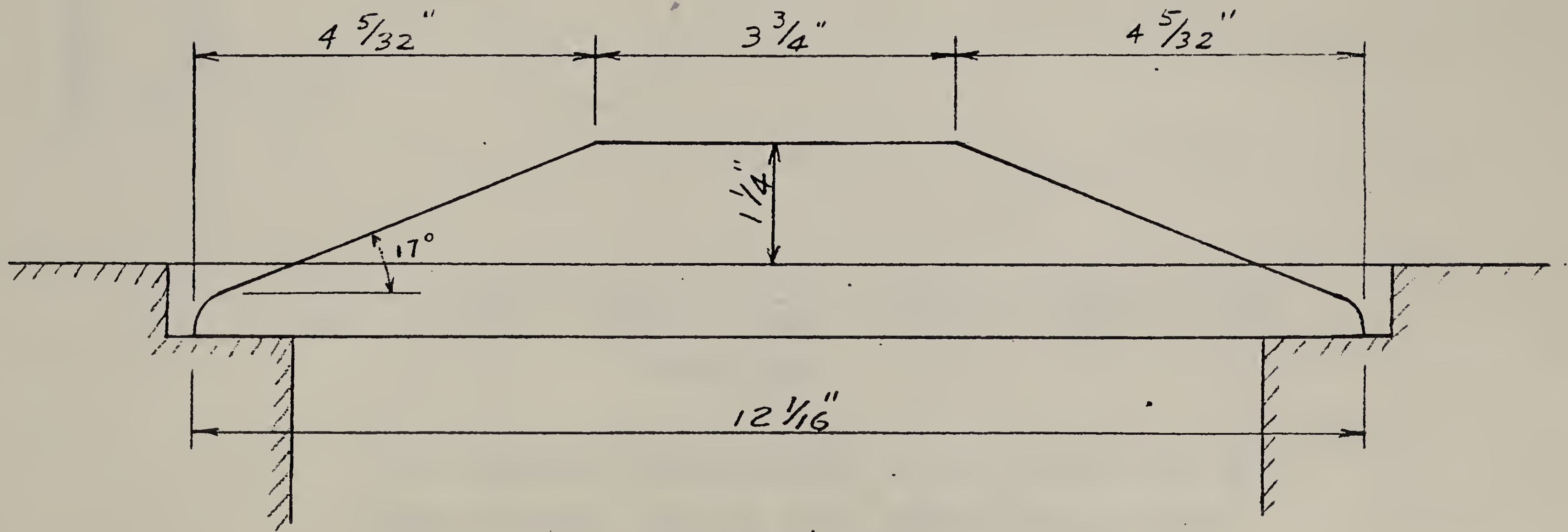
/s/ L. K. Irwin

L. K. Irwin,
Mechanical Engineer,
Engineering Mechanics Section.

Enclosures



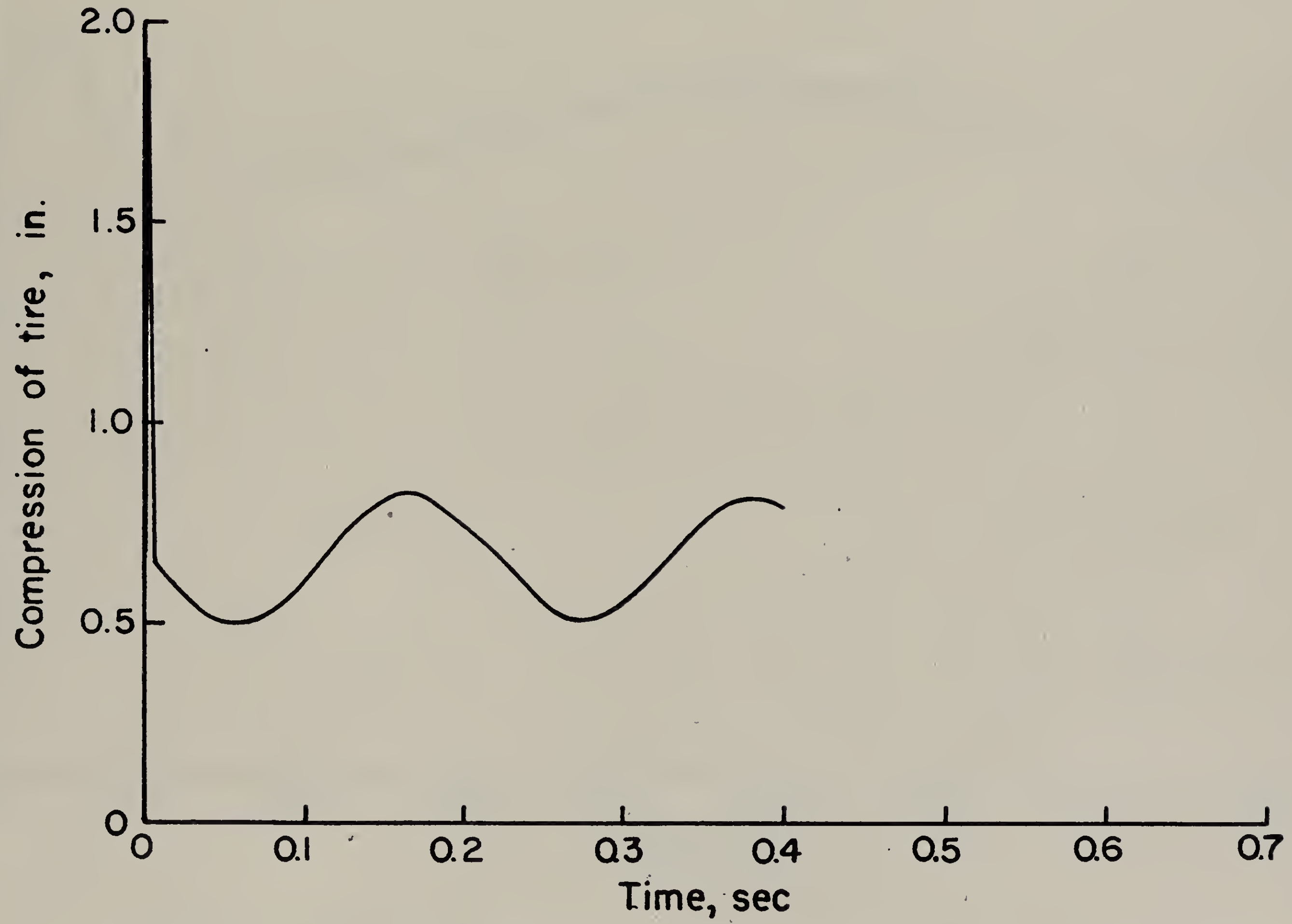
Sketch A



Sketch B

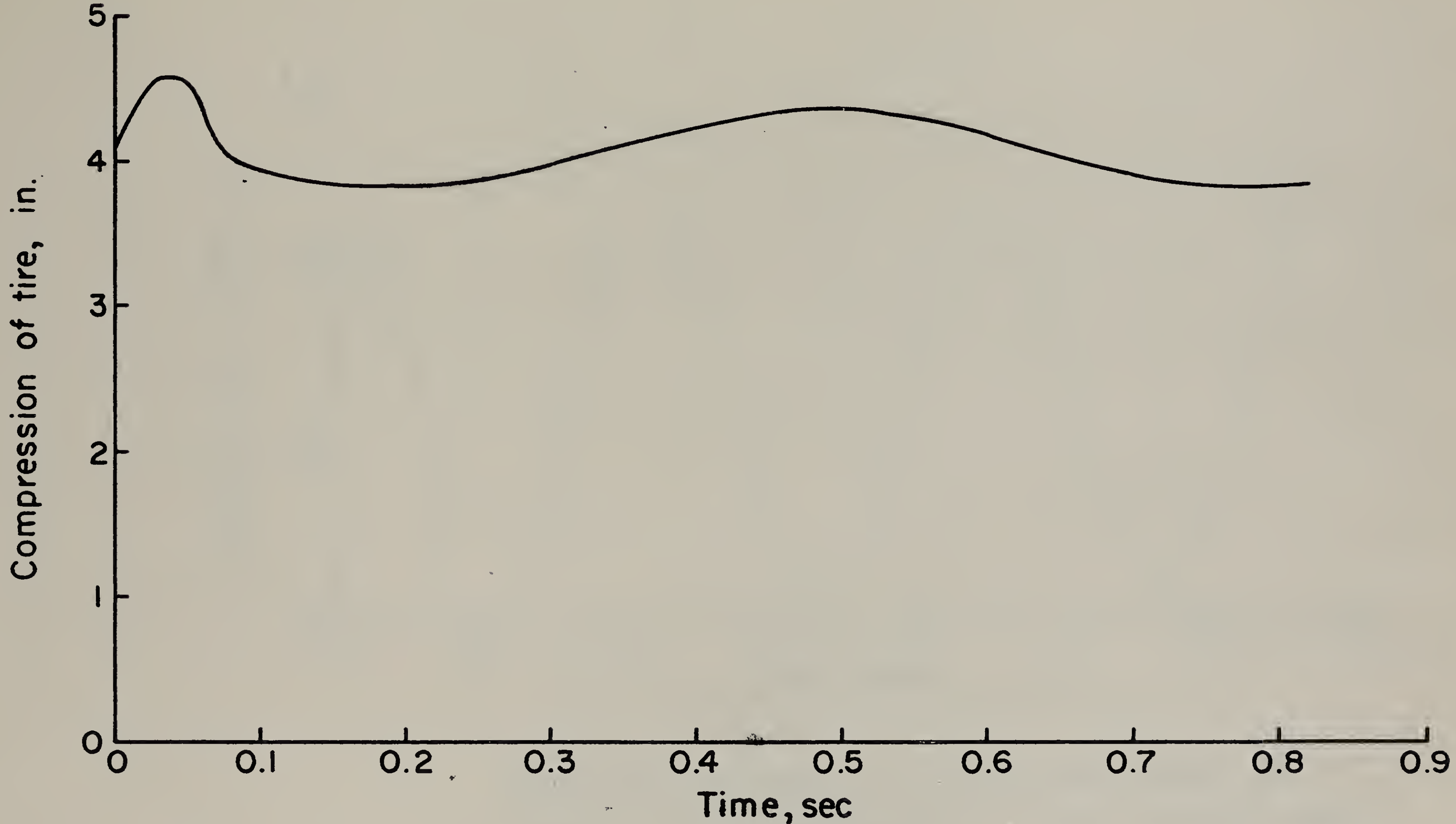
May 29, 1957

Figure 4



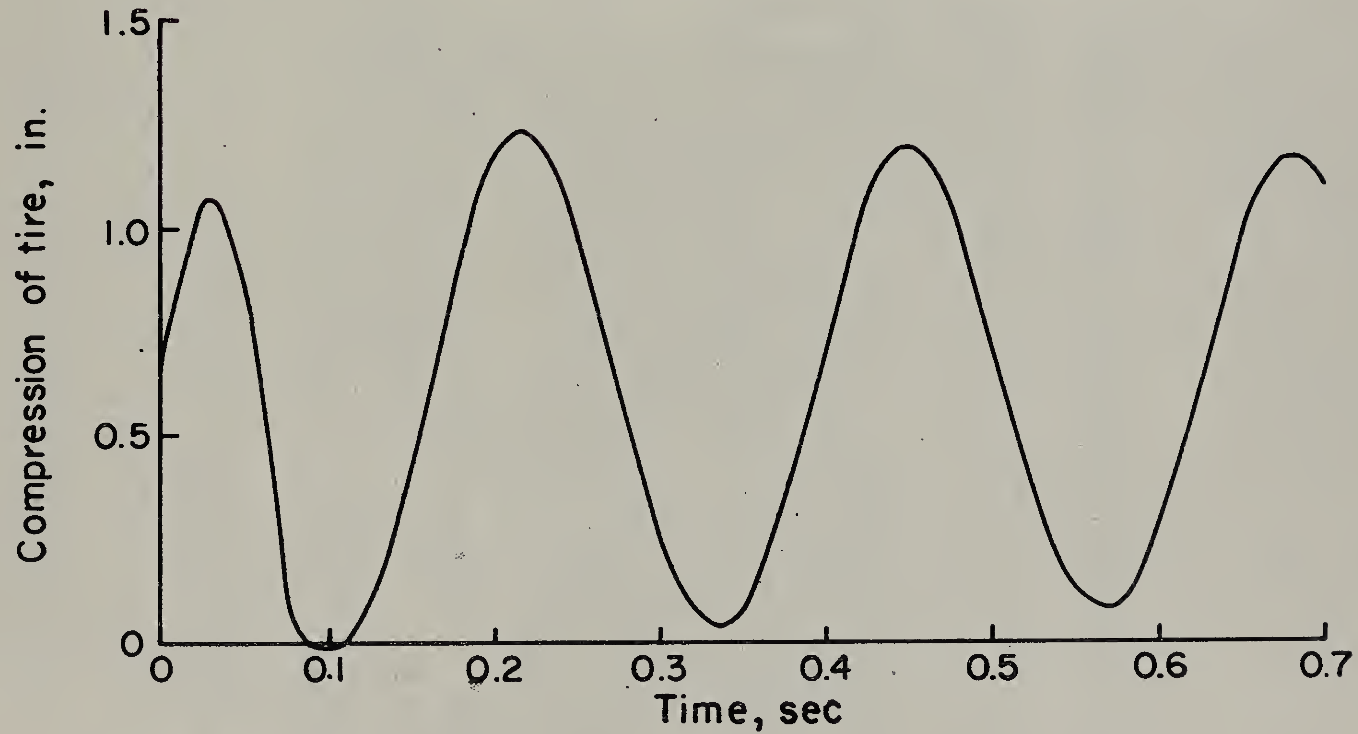
Time history of compression of nose wheel tire of F-86 airplane taxying over Westinghouse light at 110 mph. Maximum height of light = 1.25 in.

Figure 5



Time history of compression of main wheel tire of B-47 airplane taxying over model C Elfaca light at 110 mph. Maximum height of light = 0.50 in.

Figure 6



Time history of compression of nose wheel tire of F-86 airplane taxying over model C Elfaca light at 110 mph. Maximum height of light = 0.50 in.

Figure 7

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside front cover of this report.

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Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

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Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

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Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

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Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

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