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# RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

## GUST-TUNNEL INVESTIGATION TO DETERMINE THE LOAD AT THE JOINT OF A COUPLED AIRPLANE CONFIGURATION ENCOUNTERING A GUST

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# GUST-TUNNEL INVESTIGATION TO DETERMINE THE LOAD AT THE JOINT OF A COUPLED AIRPLANE CONFIGURATION ENCOUNTERING A GUST

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## SUMMARY

An investigation has been made in the Langley gust tunnel with two identical airplane models approximating $\frac{1}{40}$-scale models of the B-29, coupled in tandem with a boom so that the individual centers of gravity were equidistant from the single coupling joint at the tail of the lead airplane. Time histories of the boom joint load were obtained as the models were flown through a gust. The results indicate that on a similar configuration involving airplanes the size of B-29 airplanes a load on the boom joint of 10,000 to 14,000 pounds could be induced by encountering a gust of 50 feet per second and having a gradient distance of 17 chords, at a forward speed of 380 feet per second and that the total load is extremely sensitive to the steadiness of flight that can be maintained with or without a gust. It is felt that the results are probably satisfactory to show order of magnitude, but it does not appear possible that a precise determination of the joint load that would be applicable to the full-scale airplanes can be obtained by gust-tunnel tests.

## INTRODUCTION

One of the problems confronted in the operation of military aircraft at present is that of range extension. Various means have been investigated to accomplish this end, including droppable auxiliary fuel tanks, towing one or more airplanes by another, and refueling in flight. Refueling in flight seems to be best suited in many respects for use by large aircraft such as bombers.

One configuration proposed for in-flight refueling of large airplanes consists of two airplanes of equal or approximately equal size, coupled in tandem by a large-diameter boom which permits rapid transfer of the fuel. The boom is rigidly attached to the nose of the rear airplane, and is coupled to the tail of the lead airplane by a joint which permits limited angular freedom of motion. Such a configuration poses a number of operational and design problems, including the determination of the loads produced in the boom and joint by flight through turbulent air.

In an attempt to provide some information on the joint loads, an investigation was made in the Langley gust tunnel of the tandem-coupled configuration using models which were approximately $\frac{1}{40}$-scale models of the B-29 airplane. The pitching moment of inertia of the models, however, was about 3 times the scale value of the moment of inertia of the actual airplane. Seven flights, which were intended to be repeat flights under the same conditions, were made through a gust corresponding to a full-scale gust of about 50 feet per second having a gradient of about 17 chords.

This paper presents time histories of the load at the joint and of the pitch increment of the models for each of the seven gust flights and for three flights with no gust.

## APPARATUS

Figure 1 is a photograph showing the general configuration of the models, and table I gives the major characteristics of the models as compared to those of the full-scale B-29 airplane and to values for a true $\frac{1}{40}$-scale model of that airplane. The most outstanding differences between the models used and an actual $\frac{1}{40}$-scale model of the B-29 airplane were that the test models had low wings instead of midwings, and the pitching moments of inertia of the models were about 3 times the $\frac{1}{40}$-scale value. As a result of preliminary flights made to determine the optimum center-of-gravity positions for steady flight, the centers of gravity were placed at 23 percent and 28 percent of the mean geometric chord of the lead model (model I) and the trailing model (model II), respectively, for all the test flights.

The connecting boom was rigidly attached to the nose of model II and was pin jointed at the tail of model I so as to allow some movement

in the pitch direction. The length of the boom was such that the centers of gravity of the two models were equidistant from the pin joint. As a result, corresponding points on the two models were 9.8 mean chords apart.

A variable-inductance type of pickup to measure the normal load at the boom joint was located in the tail of model I and the boom was pinned to this unit. Model I was also equipped with a single-channel telemeter to transmit a record of the load to the receiving station. Figure 2 shows the pickup and transmitter.

A description of the gust tunnel and its equipment is given in reference 1. The forward velocity and time histories of pitch increment for the models were obtained as described in reference 2.

## TESTS

All flights were made with a forward velocity of 60 feet per second (380 fps at full scale). The models were first flown with no gust in order to obtain the best possible trim conditions. It was found that the models were extremely sensitive to small changes in trim; in fact, no condition was found that would give essentially zero load in free flight. The test flights were made as follows: A flight with no gust was made, followed by three consecutive flights through a gust having the profile shown in figure 3 and a peak velocity of 8 feet per second. (This peak velocity corresponds to a full-scale value of 50 fps.) On the third gust flight, one of the models was damaged in the arresting curtains. The model was repaired and the configuration retrimmed. The tests were then completed by making a flight with no gust, four gust flights, and a final flight with no gust, in succession. Time histories of the normal joint load and of the pitch of each model, and measurements of the forward speed and maximum gust velocity, were obtained for each flight.

A natural frequency of vibration was found to occur in the coupled configuration because of the elasticity of the connecting boom. This natural frequency was determined by suspending the models with strings attached at the individual centers of gravity and making a telemeter record of the joint load as the models were tapped at various points.

## PRECISION

The measured quantities are estimated to be accurate within the following limits for any single flight:

| | Model | Full Scale |
|---|---|---|
| Boom joint load, pounds . . . . . | ±0.03 | ±1920 |
| Forward velocity, feet per second . . . . . | ±0.50 | ±3.16 |
| Gust velocity, feet per second . . . . . | ±0.10 | ±0.63 |
| Pitch-angle increment, degree . . . . . | ±0.20 | ±0.20 |

In a series of successive flights, minor variations in launching speed or attitude of the models introduce extraneous motions of the models which cause variations in the joint load. It is not possible at this time to correct these variations. Furthermore, the inability to trim the configuration for straight flight leads to the expectation that results from successive repeat flights might not be identical.

## RESULTS AND DISCUSSION

Time histories of the normal load at the boom joint and of the pitch-angle increment of each model as functions of mean chords of travel into the gust were evaluated for each flight. A sample of each type of telemeter record (natural frequency, no-gust flight, and gust flight) is shown in figure 4. Inspection of these records indicates that the oscillations in the telemeter records are at the natural frequency of the system. The curves of joint load for the flights are presented in figure 5 and represent faired curves which exclude these oscillations. The curves of figure 5 show the variation in joint load from the leading edge of the gust tunnel for the two groups of flights through similar gusts. An upward load on the end of the boom is represented in the positive sense.

The maximum increment in load on the boom joint due to the gust and the corresponding full-scale values for each flight are given in table II. These values were obtained from figure 5 by assuming each record of the gust flights to contain the load obtained with no gust with the gust load superimposed upon it. The maximum and minimum values of load in table II, 0.22 pound and 0.16 pound, are within the range of estimated accuracy of measurement (±0.03 lb). The scale-up factor for force is $40^3$ and, therefore, these maximum and minimum values would correspond to about 14,000 pounds and 10,000 pounds, respectively, for the full-scale airplanes. The full-scale conditions for which these forces were predicted are a forward speed of about 380 feet per second, and a gust having a maximum velocity of 50 feet per second and a gradient distance to peak velocity of about 17 chords. In the model flights, the

peak load occurred at about the time the tail of model I was at the point of peak gust velocity. The effects of the gust-gradient distance are not known and cannot be readily determined; however, for a given gust-gradient distance, the magnitude of the joint load should vary directly with gust velocity.

Examination of the curves given in figure 5 reveals that the time histories of joint load for the two groups of flights were somewhat different after the maximum was attained. It was not possible to determine whether this difference resulted from the damage of the model during the third gust flight or from some other source. It seems significant to note, however, that the peak loads, which should be of primary interest in this investigation, are reasonably consistent for all the test flights.

Since the moments of inertia of the models were higher than the $\frac{1}{40}$-scale value, there was some doubt as to whether the scaled-up values of joint load obtained from the tests would apply to a similar configuration with airplanes the size of B-29 airplanes. A rigorous analysis to determine the effect of the pitching moment of inertia on the joint load was not made because of the complexity of the problem, but a simplified analysis was made to determine these effects, at least qualitatively. It is seen in figure 5 that the maximum load occurred at about the time the tail of model I was at the point of peak gust velocity. From this observation it was assumed that the major portion of the joint load due to the gust is contributed by the tail of the lead airplane. The simplified analysis neglected the effects of the unsteady motions of the models. The results showed that having the moments of inertia of the models 3 times the true scale value might increase the load on the joint by about 20 or 25 percent.

Inspection of figure 5 indicates that over certain ranges of penetration the load for the no-gust condition can be equal to or greater than the gust load in the boom. This condition results from the fact that completely steady flight could not be obtained even though extreme care was taken in trimming the models. If the same difficulty of obtaining steady flight occurs for the full-scale airplanes as occurred in these tests and in those of reference 3, it would appear that loads as great as those produced by gusts might develop even in smooth air.

As a matter of completeness, the available histories of pitch increment for each model are presented in figure 6, and figure 7 shows the relative pitch of the models, that is, the pitch increment of model I with respect to that of model II. The scatter of the data does not allow an estimate to be made of the effect of pitch on the joint load due to the gust.

As indicated by the scatter of the load data, the results presented in this paper are probably satisfactory to show order of magnitude, but it does not appear possible that a precise determination of the joint load that would be significant for the full-scale airplanes can be obtained by gust-tunnel tests. The inconsistency of the data appears to result from the lack of stability of the configuration. The fine degree of trim settings necessary to fly the models was very difficult to attain. The small disturbances associated with launching the models, which cause only minor effects for the usual gust-tunnel tests, appear to introduce divergent stability reactions with this coupled airplane configuration.

## CONCLUDING REMARKS

Flights were made in the Langley gust tunnel of two identical airplane models coupled in tandem by a boom rigidly attached to the nose of the trailing airplane and pin jointed to the tail of the lead airplane. The results of the tests indicated that a load on the connecting joint of 10,000 to 14,000 pounds might be induced on a similar configuration involving airplanes the size of B-29 airplanes, in a 50-foot-per-second gust having a gradient distance of 17 chords and for a forward speed of 380 feet per second. The total load appeared to be extremely sensitive to the steadiness of flight that could be maintained with or without a gust. It is felt that the results are probably satisfactory to show order of magnitude, but it does not appear possible that a precise determination of the joint load that would be applicable to the full-scale airplanes can be obtained by gust-tunnel tests.

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## REFERENCES

1. Donely, Philip: Summary of Information Relating to Gust Loads on Airplanes. NACA Rep. 997, 1950. (Formerly NACA TN 1976.)

2. Donely, Philip: An Experimental Investigation of the Normal Acceleration of an Airplane Model in a Gust. NACA TN 706, 1938.

3. Shanks, Robert E. and Grana, David C.: Investigation of the Dynamic Longitudinal Stability of Two Equal-Size Models Coupled in Tandem with a Single Joint. Preliminary Model Flight Tests. NACA RM L50H17, 1950.

TABLE I

CHARACTERISTICS OF FULL-SCALE B-29, $\frac{1}{40}$-SCALE B-29, AND MODELS USED

| Item | Full-scale values | $\frac{1}{40}$-scale values | Model values |
|---|---|---|---|
| Wing span, ft . . . . . | 141.23 | 3.53 | 3.53 |
| Root chord, ft . . . . . | 17.00 | 0.42 | 0.42 |
| Tip chord, ft . . . . . | 7.42 | 0.18 | 0.18 |
| MGC, ft . . . . . | 12.87 | 0.32 | 0.32 |
| Area, sq ft . . . . . | 1738.88 | 1.08 | 1.08 |
| Aspect ratio . . . . . | 11.6 | 11.60 | 11.60 |
| Fuselage length, ft . . . . . | 99.0 | 2.48 | 2.38 |
| Horizontal tail span, ft . . . | 43.0 | 1.07 | 1.08 |
| Horizontal tail area, sq ft . | 333.0 | 0.20 | 0.22 |
| Weight, lb . . . . . | 120,000 | 1.87 | 2.50 |
| Moment of inertia, in pitch, slug-ft$^2$ . . . . . | 800,000 | 0.008 | 0.024 |

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TABLE II

MAXIMUM INCREMENT IN JOINT LOAD DUE TO GUST FOR EACH FLIGHT

| Flight | Maximum increment in joint Load due to gust (lb) | Corresponding full-scale value (lb) |
|---|---|---|
| 1 | 0.16 | 10,240 |
| 2 | .16 | 10,240 |
| 3 | .18 | 11,520 |
| 4 | .18 | 11,520 |
| 5 | .22 | 14,080 |
| 6 | .21 | 13,440 |
| 7 | .18 | 11,520 |
| | Average: 0.18 | |

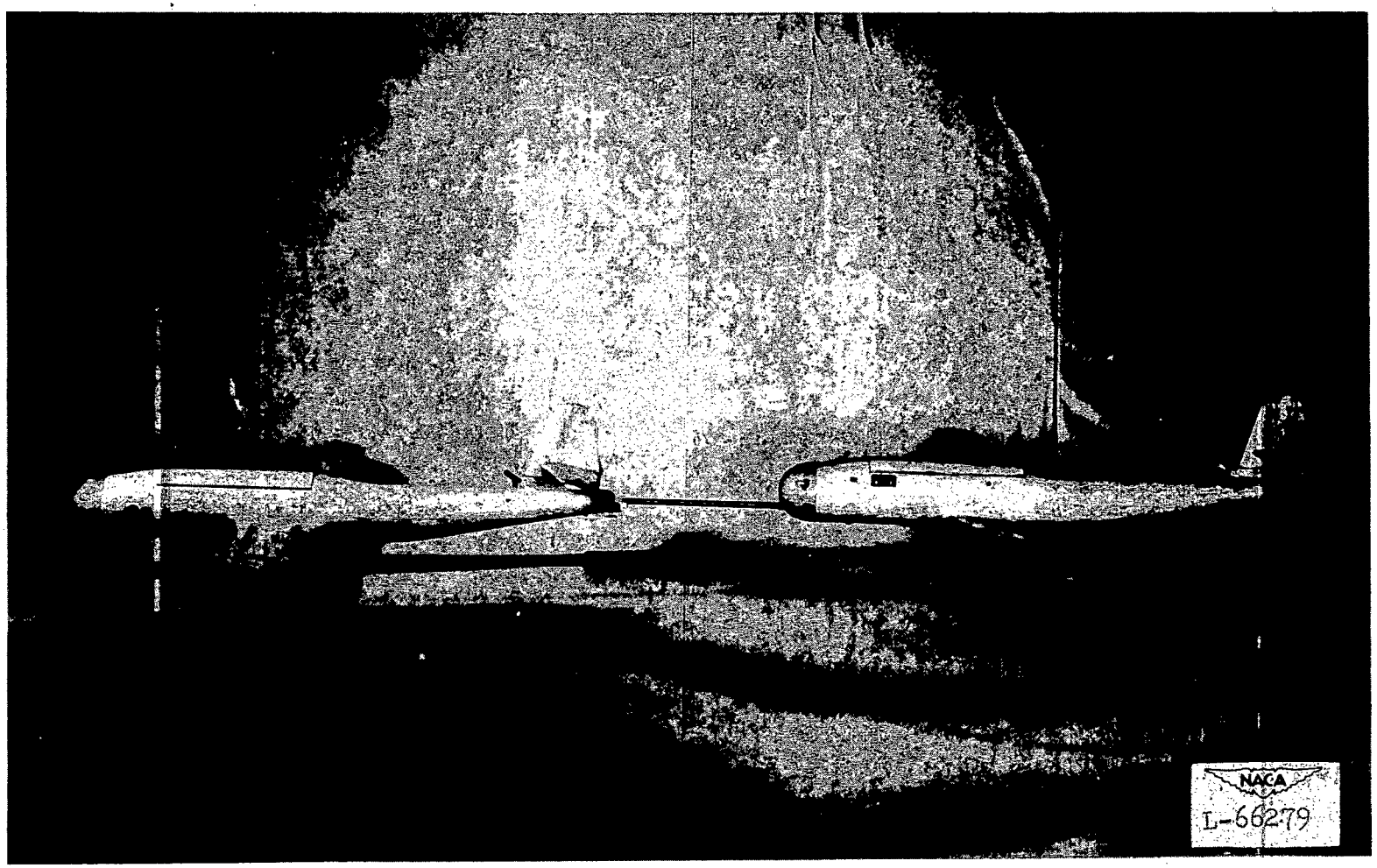
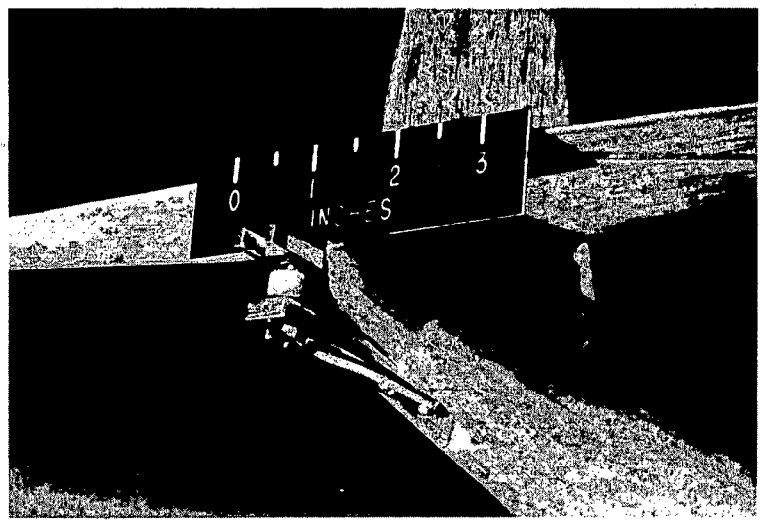



Figure 1.- General configuration of models.

[redacted]




(a) Pickup in tail of model I.

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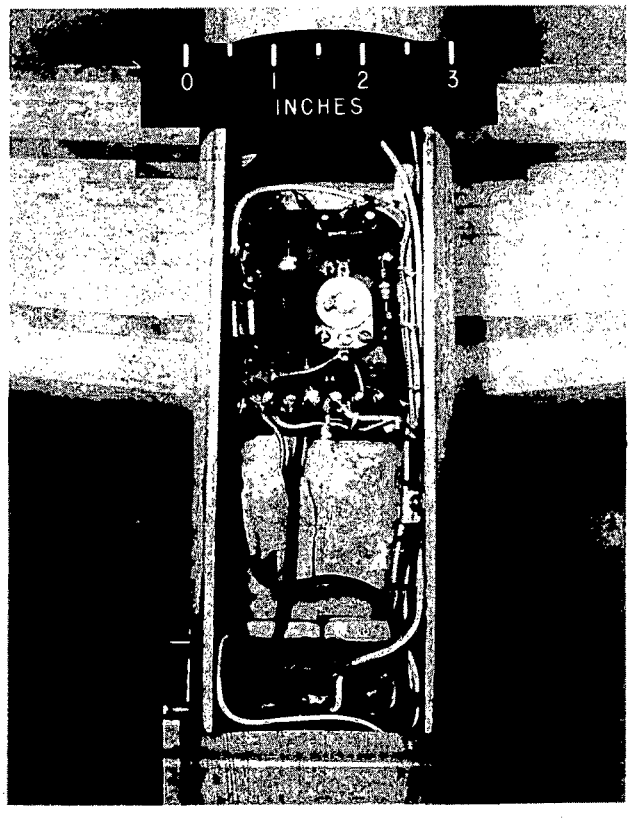


(b) Transmitter.

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Figure 2.- Views of instruments in model I.

[redacted]

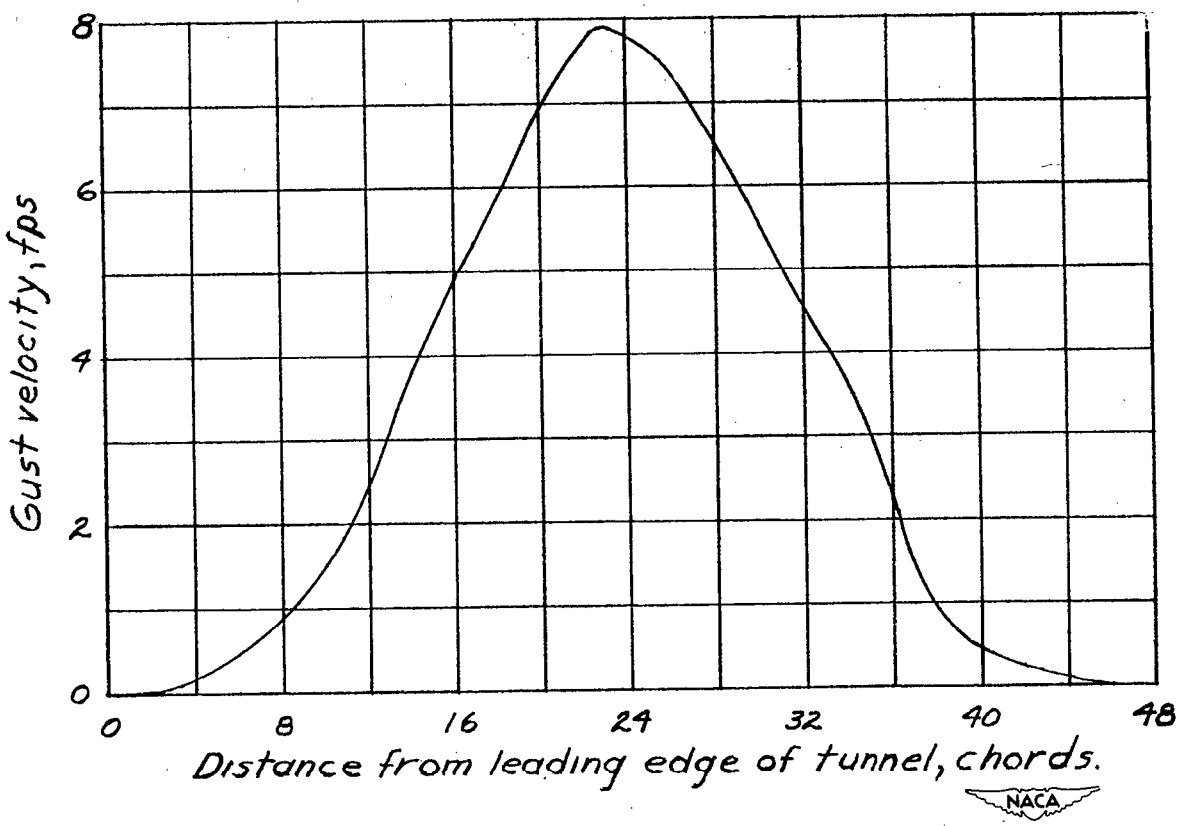
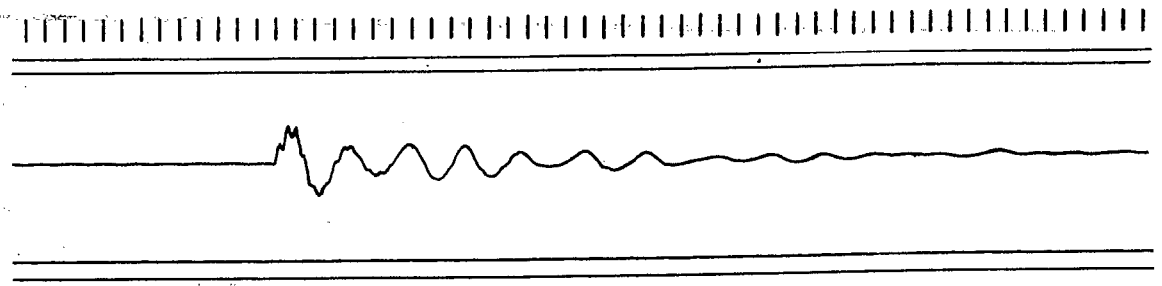
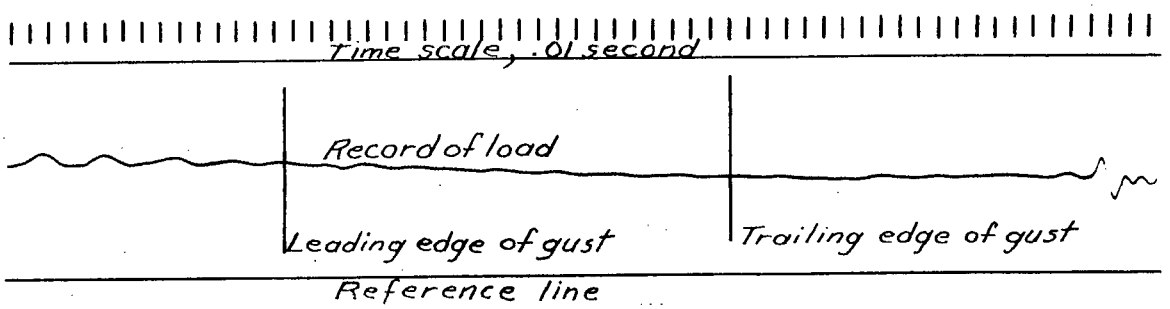


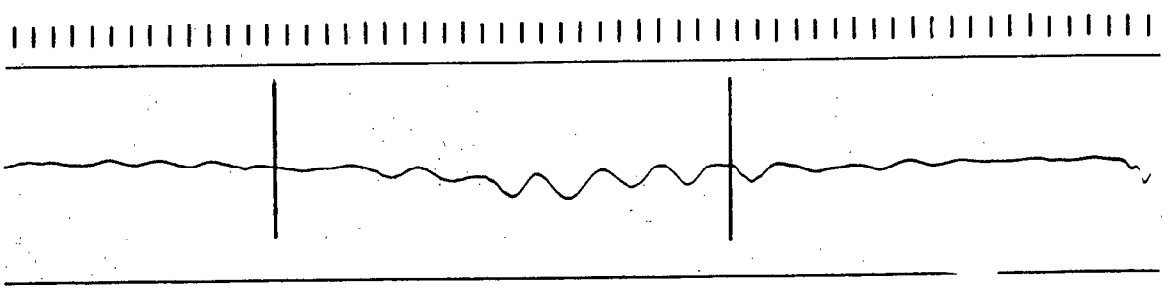

Figure 3.- Profile of gust used in tests.



(a) Natural frequency test record.

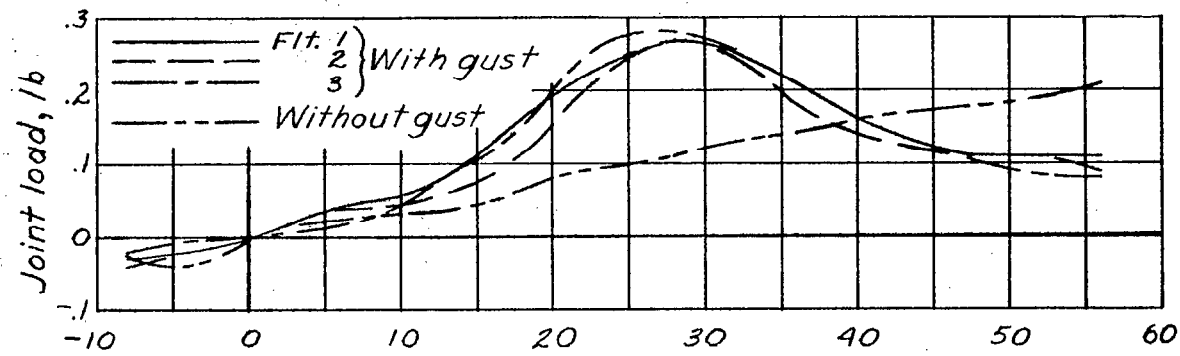



(b) Flight without gust.

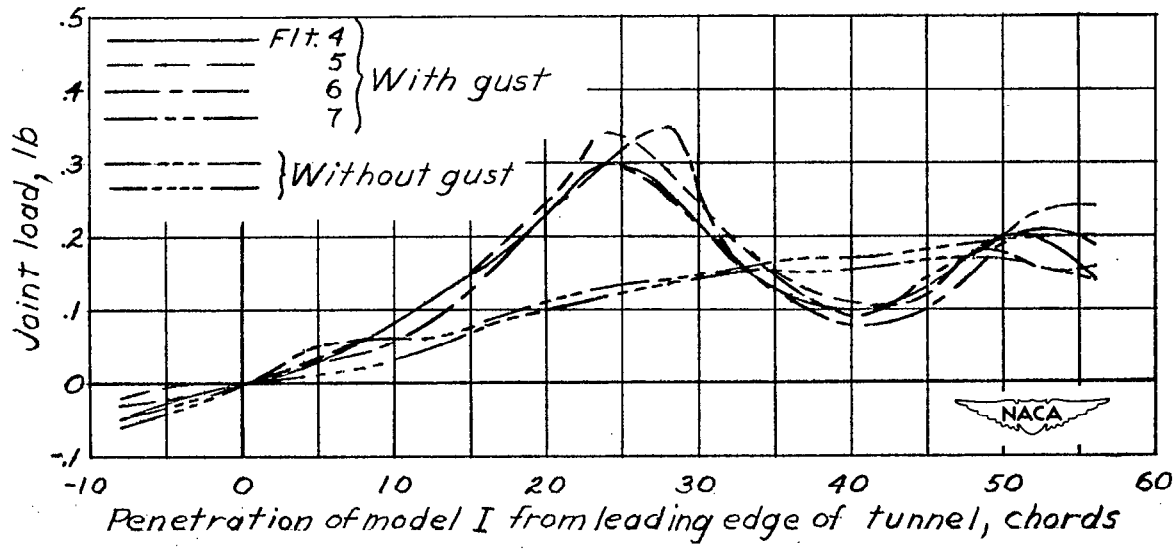


(c) Flight with gust.

Figure 4.- Sample telemeter records.

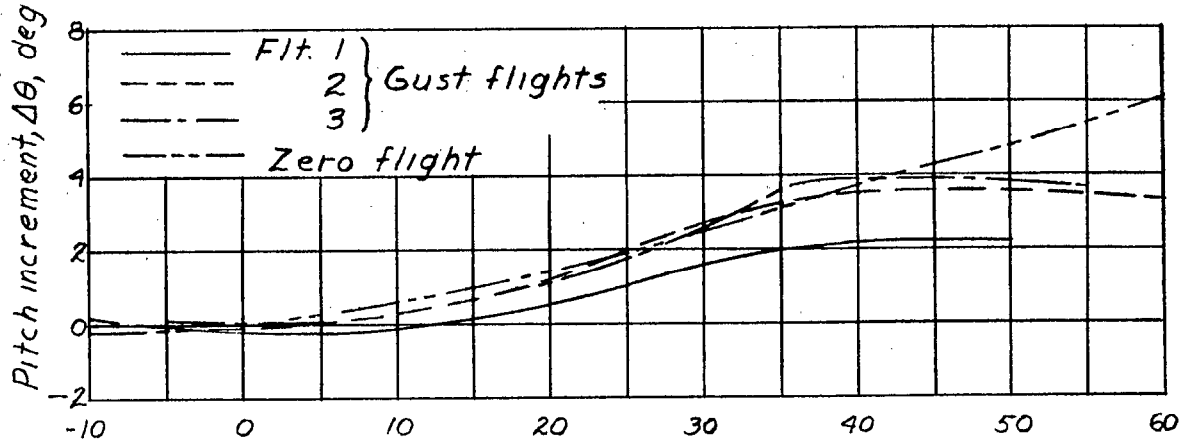



(a) Flight group A.

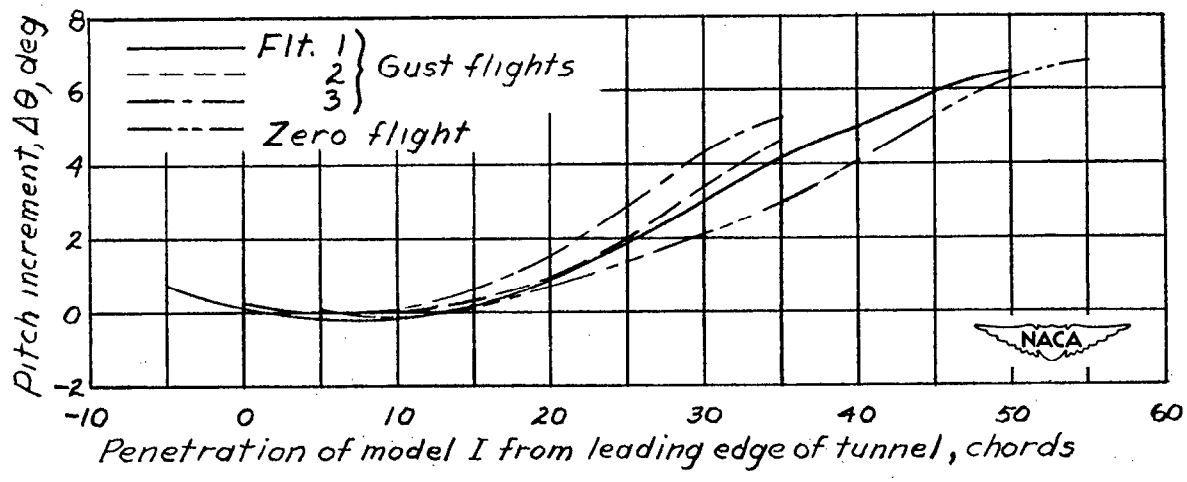



(b) Flight group B.

Figure 5.- Histories of boom-joint load due to gust.

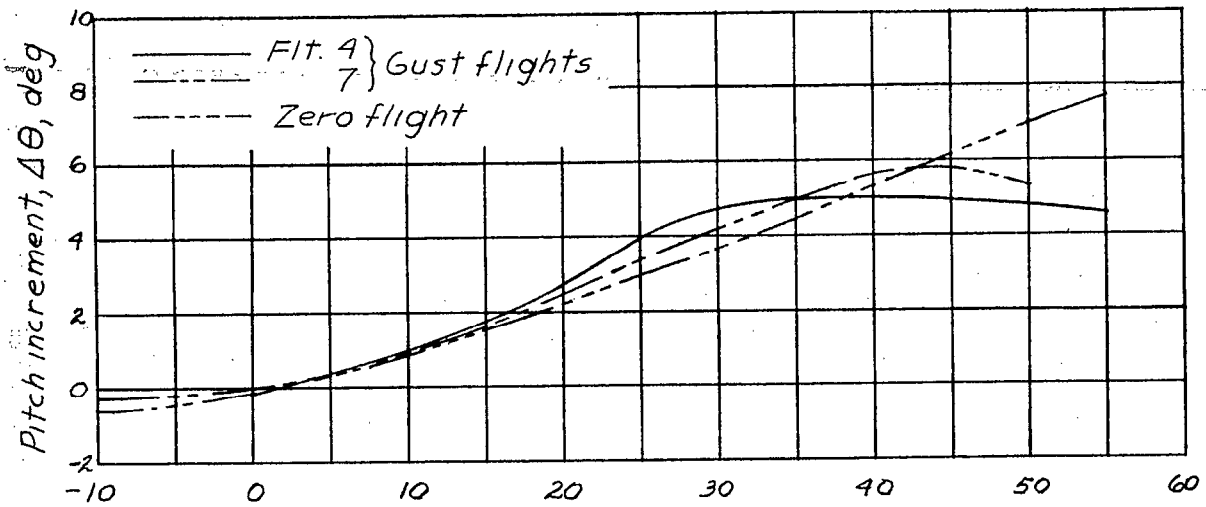



(a) Model I, flight group A.

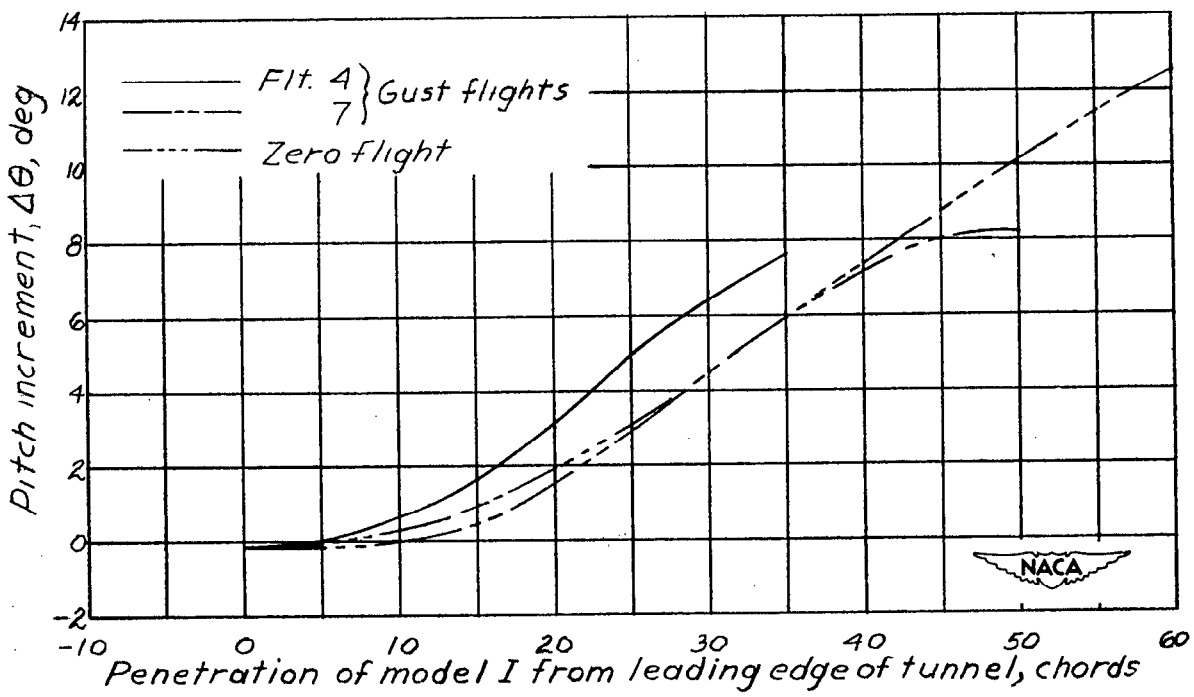



(b) Model II, flight group A.

Figure 6.- Histories of pitch increment of models.

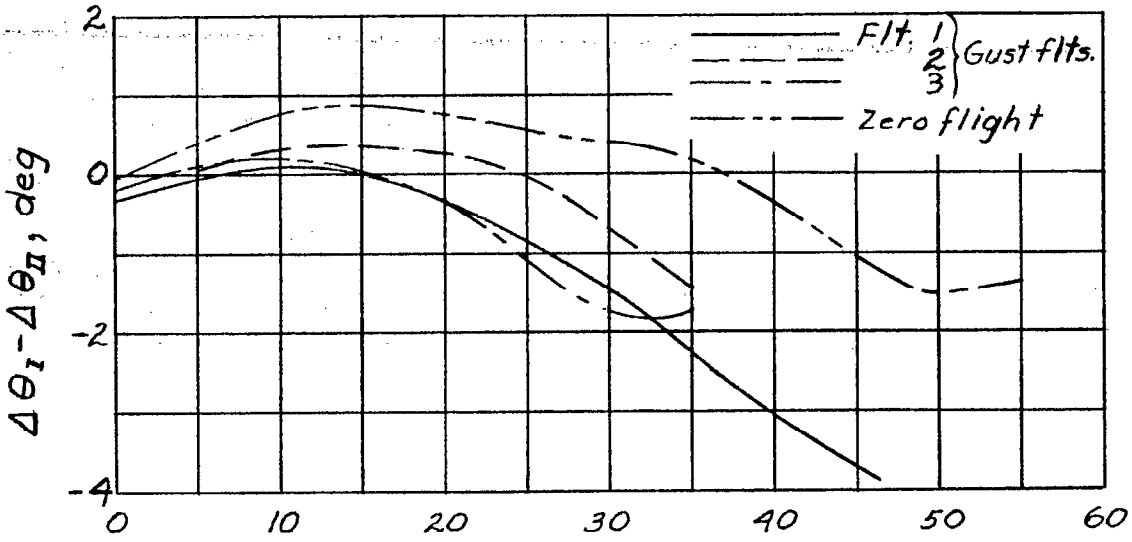



(c) Model I, flight group B.

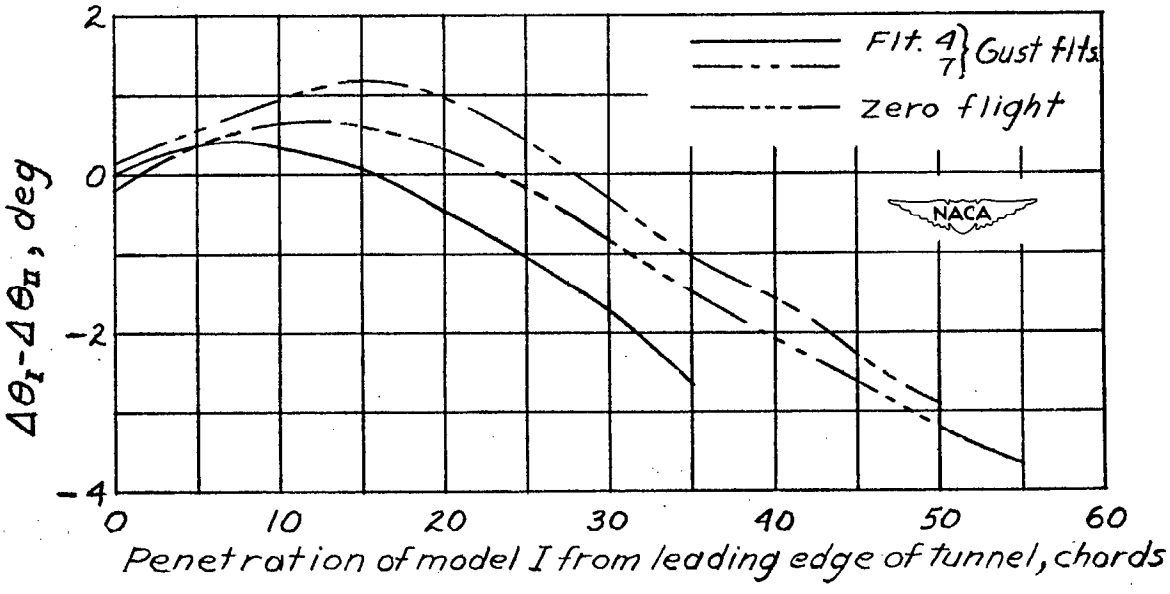



(d) Model II, flight group B.

Figure 6.- Concluded.




(a) Flight group A.




(b) Flight group B.

Figure 7.- Pitch increment of model I relative to that of model II.