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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE 2949

# A VARIABLE-FREQUENCY LIGHT SYNCHRONIZED WITH A HIGH-SPEED MOTION-PICTURE CAMERA TO PROVIDE VERY SHORT EXPOSURE TIMES

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## SUMMARY

A new high-speed photographic technique has been developed which employs a variable-frequency light synchronized with a commercially available 16-millimeter high-speed motion-picture camera without appreciable alterations to the camera. The technique is described and results obtained by this technique of photographing the flow past models in a wind tunnel employing the schlieren method of flow visualization are presented. The photographs show that the new technique, through the use of extremely short exposure times (about 4 microseconds), provides more sharply defined pictures throughout the flow field than were obtained by conventional techniques.

## INTRODUCTION

There have been various adaptations of high-speed motion-picture photography to the solution of the problem of obtaining time histories of rapid motions (refs. 1 to 7). These solutions have involved compromises between exposure time, time interval between exposures, and total duration of the time history recorded. Generally speaking, the exposure time is inversely proportional to the film speed or number of frames per second. In high-speed motion-picture photography, where the time interval between recorded pictures is very small or the number of frames per second is very large (above 10,000 frames per second), the length of film is drastically reduced (see refs. 1, 4, and 6) because of mechanical and structural limitations.

In order to obtain the time history of the rapid growth or decay of a particular motion, the motion has to be recorded with extremely short time intervals between pictures and, because of the resulting short film length, the period of time covered is extremely short. Furthermore, several separate records are required to determine whether the particular motion recorded is a complete cycle and truly representative

of all such motions. Experience in aerodynamic investigations, however, has indicated that the motions encountered often have an over-all cyclic character such that, even though their frequencies may vary in somewhat random fashion, the nature of the motion can often be adequately defined when a large number of exposures or a long time history is obtained with moderate time intervals between exposures. The exposure time of each of the pictures taken with standard commercially available photographic equipment (see, for example, ref. 5), at film speeds around 300 frames per second (exposure time around 0.001 seconds), produces some blurring of those parts of the recorded motion which involve appreciable displacement during the exposure. This difficulty is accentuated when low initial contrast with the background occurs.

One approach to the solution of this problem is the self-synchronizing stroboscopic schlieren system described in reference 8. This system used a short-duration flashing light that was triggered by an auxiliary schlieren system employing a phototube which caused the light to flash when a given light density or change occurred on the face of the tube. The system was further modified to provide progressive time delays between the signal and the flashing of the light, thereby providing some information on the changes with time. The system, however, was limited to cyclic phenomena and required the size and shape of each disturbance to be nearly the same and also required that the time history of each disturbance be approximately the same for each cycle. The self-synchronizing stroboscopic system, therefore, precluded the possibility of obtaining a straightforward time history of a motion, especially a motion involving variations in frequency.

A system was devised during the year 1951 wherein a 16-millimeter moving-picture camera like the one described in reference 5 was modified to control electronic equipment to provide pulsing power to a mercury-vapor lamp. The lamp flashes with a duration of approximately four microseconds and a frequency that coincides with the number of frames per second of the camera. The purpose of the present paper is to describe this system and to present some photographic results to illustrate the manner of its function.

## APPARATUS

The 16-millimeter camera was modified by the addition of a generator attached to the camera drive system as shown in figure 1. The generator produces signals to control the rate of flashing of the light source. The electronic equipment utilized to produce the variable-frequency light is shown by a block diagram in figure 2. Wiring diagrams of the various components are shown in figures 3 to 6.

Camera.- The camera is a 16-millimeter Western Electric Fastax camera in which the internal rotating prism that acts as a shutter has been retained. The prism serves a dual purpose: First, by shutter action the prism permits correct adjustment of phasing between signal and film position to place properly the image on the film for projection; second, the rotating prism optically compensates for all slight variations in the time intervals between the time the film is in correct position and the light flashes, inasmuch as the prism optically maintains a truly equal spacing between picture centers on the film, or provides register between picture formation and film frame.

The camera was modified by attaching a generator to the film drive shaft (fig. 1). The rotating part of the generator consists of a circular steel disk on which teeth have been cut (fig. 1(b)), each tooth corresponding to one frame of the film. Near the disk and on the drive motor frame is mounted the other component of the generator, which is a pickup coil with a permanent-magnetic core (also in fig. 1(b)). As the camera operates, the toothed disk rotates and current pulses are generated in the coil as each tooth passes the face of the magnet. Phase control between open position of the shutter and flashing of the light is provided by angular adjustment of the pickup coil with respect to the toothed disk on the camera drive shaft. The induced current pulses in the coil are transmitted to the pulse amplifier.

Pulse amplifier.- The pulse amplifier is shown in figure 3. The input signal from the generator is fed into the transformer, which increases the voltage of the approximately sinusoidal generator signal. The signal is further amplified in the first stage (V1) and this amplification is accompanied by distortion of the signal wave form. The resulting signal is fed into the second stage (V2) which is a positive-feedback arrangement in the form of an overbiased multivibrator. This stage produces a square wave having a high rate of rise and fall. The square wave is converted in the third stage (V3) into a series of positive and negative pulses. The amplifier, however, is biased to saturation and the output from the third stage consists of positive pulses only. These positive pulses have a rise rate of about 150 volts per microsecond. The output of the third stage is fed into an impedance converter (V4) which provides low impedance to allow the signal pulses to be transmitted through a coaxial cable to the modulator.

Modulator.- The modulator (fig. 4) contains the power condenser, a hydrogen thyratron tube, and accessory equipment. The pulse signal from the pulse amplifier is fed into the modulator and controls the rate at which the thyratron tube discharges the condenser. The current from the power condenser is discharged through a 1000-watt mercury-vapor (H6) lamp that provides a variable-frequency light as a source of illumination and, as previously stated, this pulsing light is synchronized with the open position of the shutter of the Fastax camera. The

current path in the discharge circuit is made short and returned directly to the cathode of the hydrogen thyratron tube to minimize ground currents and radiations which might affect the pulse amplifier and cause erratic operation. The choke coil (3 microhenries), in series with the lamp, limits the peak current to protect the thyratron tube. The power condenser has a capacity of 0.2 microfarad and is charged to a voltage of 3 kilovolts by the high-voltage power supply.

Power supply.- For convenience, the high-voltage power supply was separated into a control unit (fig. 5) and a power-supply unit (fig. 6). The control unit is separated from the power-supply unit so that it can be placed in a convenient location and contains switches, meters, and indicator lamps. A circuit diagram for the high-voltage power-supply unit is presented in figure 6. This unit, as shown, converts alternating current at 110 volts into direct current at 3 kilovolts, which is the charging current for the power condenser in the modulator.

The electrical and heat dissipating characteristics of the mercury-vapor lamp fix the voltage and limit the maximum average power input to the lamp. With a sufficiently large charging rate, the average power delivered to the lamp at a constant voltage is proportional to the product of the number of flashes per second and the capacity of the condenser. The lamp requirements, therefore, necessitate a reduction in the capacity of the condenser with an appreciable increase of film speed or number of frames per second with an accompanying decrease in light output per flash.

## RESULTS AND DISCUSSION

Two photographic techniques.- Moving pictures were obtained on 16-millimeter film of the flow past models mounted in the Langley 4- by 19-inch semiopen tunnel. Flow visualization was accomplished by using a schlieren optical system in combination with the equipment previously described and with a continuous light source. The pictures taken with a mercury-vapor lamp operating continuously from a direct-current supply source are classified as having been obtained by the conventional or continuous-light technique. Consecutive frames from the 16-millimeter moving-picture film obtained by the continuous-light technique are shown in figure 7 at four film speeds, 2000, 3000, 4000, and 7000 frames per second. These conventional high-speed photographs show that the flow past a circular cylinder at a Mach number of 0.65 is very indistinct when the film speed is 2000 frames per second (exposure, 170 microseconds). As the film speed is increased, the wake from the model becomes more distinct and is fairly well defined at 7000 frames per second (exposure, 50 microseconds).

Pictures are presented in figure 8 of the flow past the circular cylinder obtained under conditions identical to those of figure 7, except that the variable-frequency-light technique was used. These pictures, taken at 300 and 540 frames per second, show that the flow throughout the field is sharply defined. Pictures of the flow obtained by both techniques are presented in figure 9. A comparison of the results obtained by the continuous-light technique at 7000 frames per second with the results obtained by the variable-frequency-light technique at 300 frames per second indicates that the variable-frequency-light technique is far superior. The superiority of this technique is evidenced by sharply defined pictures of the flow, not only in the wake of the model, but also in the region ahead of the model where disturbances generated by the vortices are seen upstream from the model. The lack of sharpness of detail in the continuous-light photographs as compared with the variable-frequency-light photographs can be ascribed primarily to the differences in exposure time between the two techniques. In the conventional or continuous-light technique the exposure time is inversely proportional to the number of frames per second and for figure 9 is roughly 50 microseconds. The exposure time for the variable-frequency-light technique, however, is independent of the number of frames per second and is approximately 4 microseconds. It may be observed in figure 7 that a factor of $3\frac{1}{2}$ in exposure time between the 7000-frames-per-second and the 2000-frames-per-second pictures had a large effect on the sharpness of detail. The sharply defined photographs obtained by the variable-frequency-light technique as shown in figure 9 prove that this new technique would be of value in high-speed schlieren photography for aerodynamic research.

Limitations on the new technique.- The variable-frequency-light technique has been used to observe the flow past models and to observe the changes in the flow that occur with changes in air speed. Inasmuch as the rate of change of air speed was moderately slow, the technique has been applied at low film speeds in order to obtain a continuous record of the flow and its changes over a reasonable range of Mach numbers. The system as presented in figures 1 to 6, however, has been checked to determine an upper limit of film speeds at which satisfactory operation is obtained. The results are illustrated by the pictures presented of the flow past an airfoil in figure 10. Reliable operation of the equipment was obtained at film speeds up to 750 frames per second. At film speeds in excess of 750 frames per second, unsatisfactory operation was encountered. The unsatisfactory operation, probably attributable to operating characteristics of the lamp, was of two types: Alternate pictures or short bursts of consecutive photographs followed by long periods of no pictures were obtained. As an illustration of the latter type, four frames from a short burst at 2160 frames per second are shown in figure 10. These four frames were taken from a strip of 40 frames followed by a blank of about 150 frames. This cycle was

repeated. A reduction in the capacity of the condenser permitted operation to film speeds of the order of 1500 to 2000 frames per second without light skipping, but the intensity of the light was too low to be photographically recorded when the high sensitivity of the schlieren system was retained (focal-length to free-aperture ratio was 5.6). It appears possible that the equipment used in the variable-frequency-light technique can be developed further for application to schlieren photography at film speeds approaching 1500 frames per second.

Other applications.- The use of a variable-frequency-light technique in the schlieren photography of air flow is one specific application. The basic technique, however, can be applied to other studies wherein rapid motions are encountered and extremely short exposure times (4 microseconds) are required to stop the motion for purposes of analysis. The system as previously discussed uses only a small portion of the total light output of the mercury-vapor lamp for its application in a schlieren system. For many other applications, the total light output from this 1000-watt lamp would provide sufficient illumination; however, when additional light is needed and multiple light sources are applicable, additional light can be obtained by duplicating a part of the modulator by providing an additional condenser and thyratron tube to operate an additional lamp. The basic circuit is believed to be adequate to operate several thyratron tubes and therefore serve several lamps operating simultaneously.

## CONCLUDING REMARKS

A new high-speed photographic technique has been developed which employs a variable-frequency light synchronized with a commercially available 16-millimeter high-speed motion-picture camera without appreciable alterations to the camera. The technique is described and results obtained by this technique of photographing the flow past models in a wind tunnel employing the schlieren method of flow visualization are presented. The photographs show that the new technique, through the use of extremely short exposure times (about 4 microseconds), provides more sharply defined pictures throughout the flow field than were obtained by conventional techniques.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 25, 1953.

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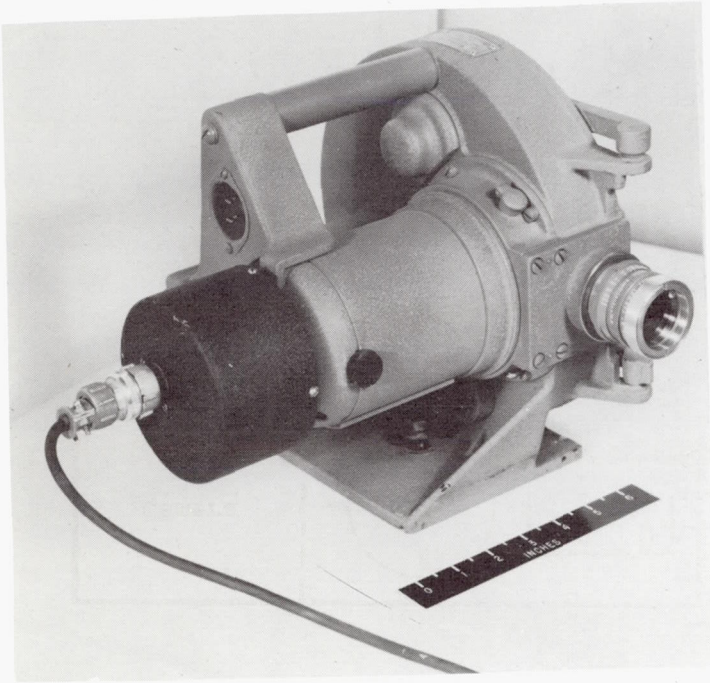
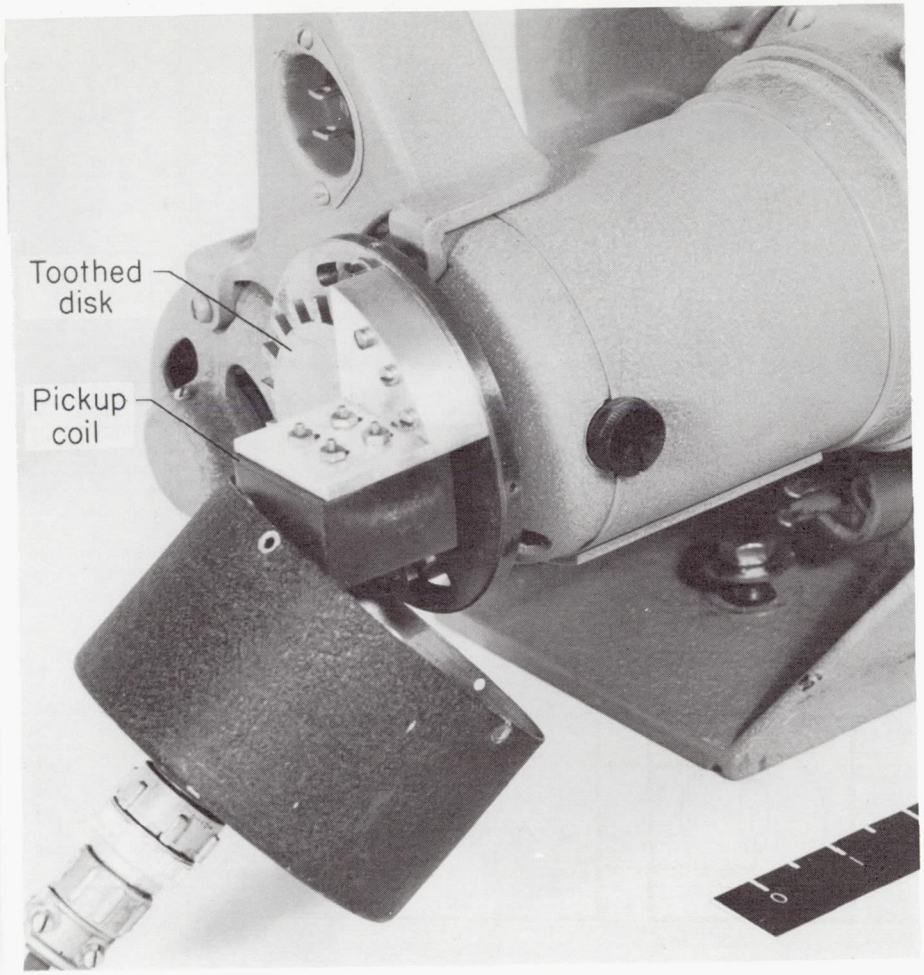


(a) Assembled.




(b) Generator cover removed.

Figure 1.- Modified camera.

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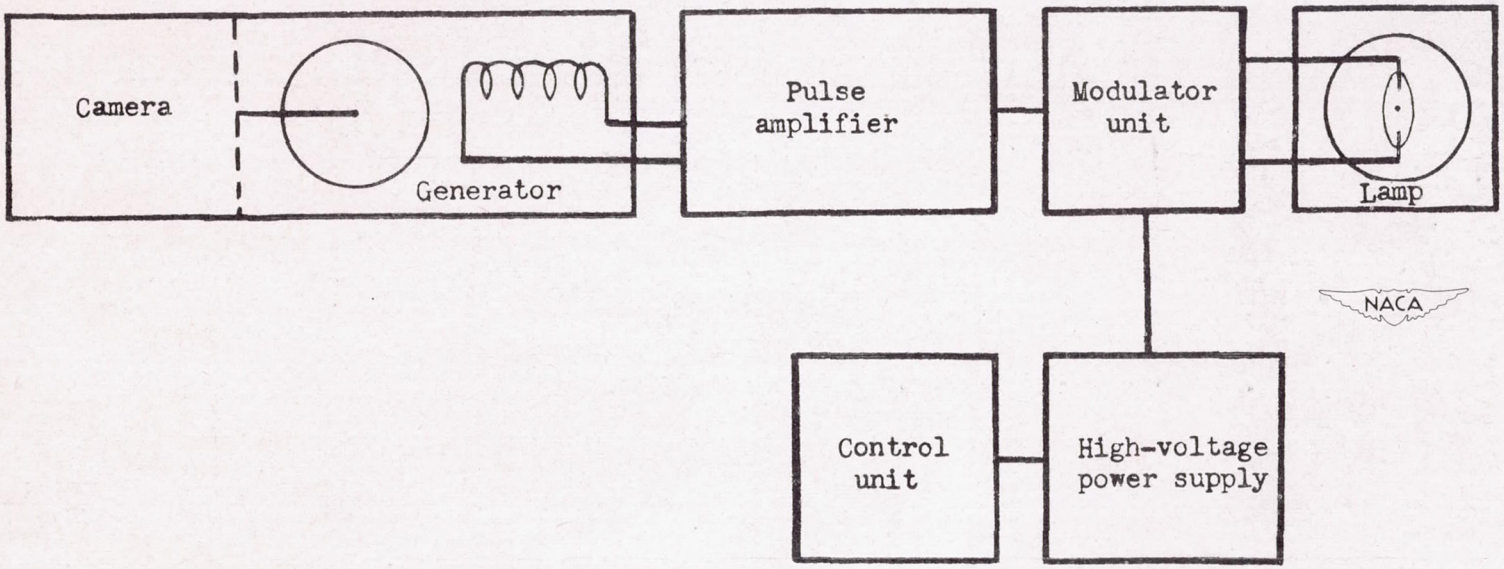


Figure 2.- Block diagram of variable-frequency light system.

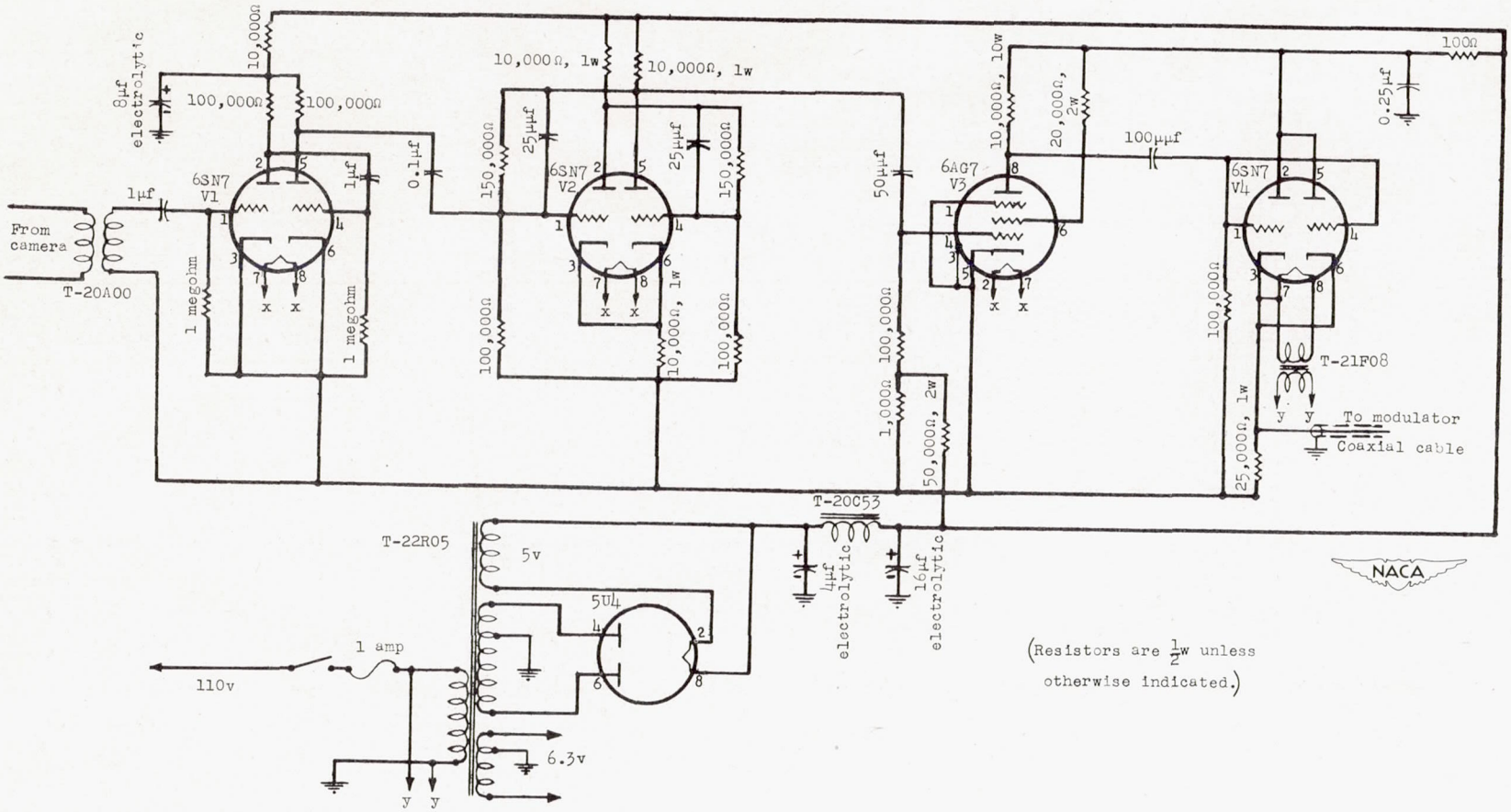


Figure 3.- Pulse amplifier.

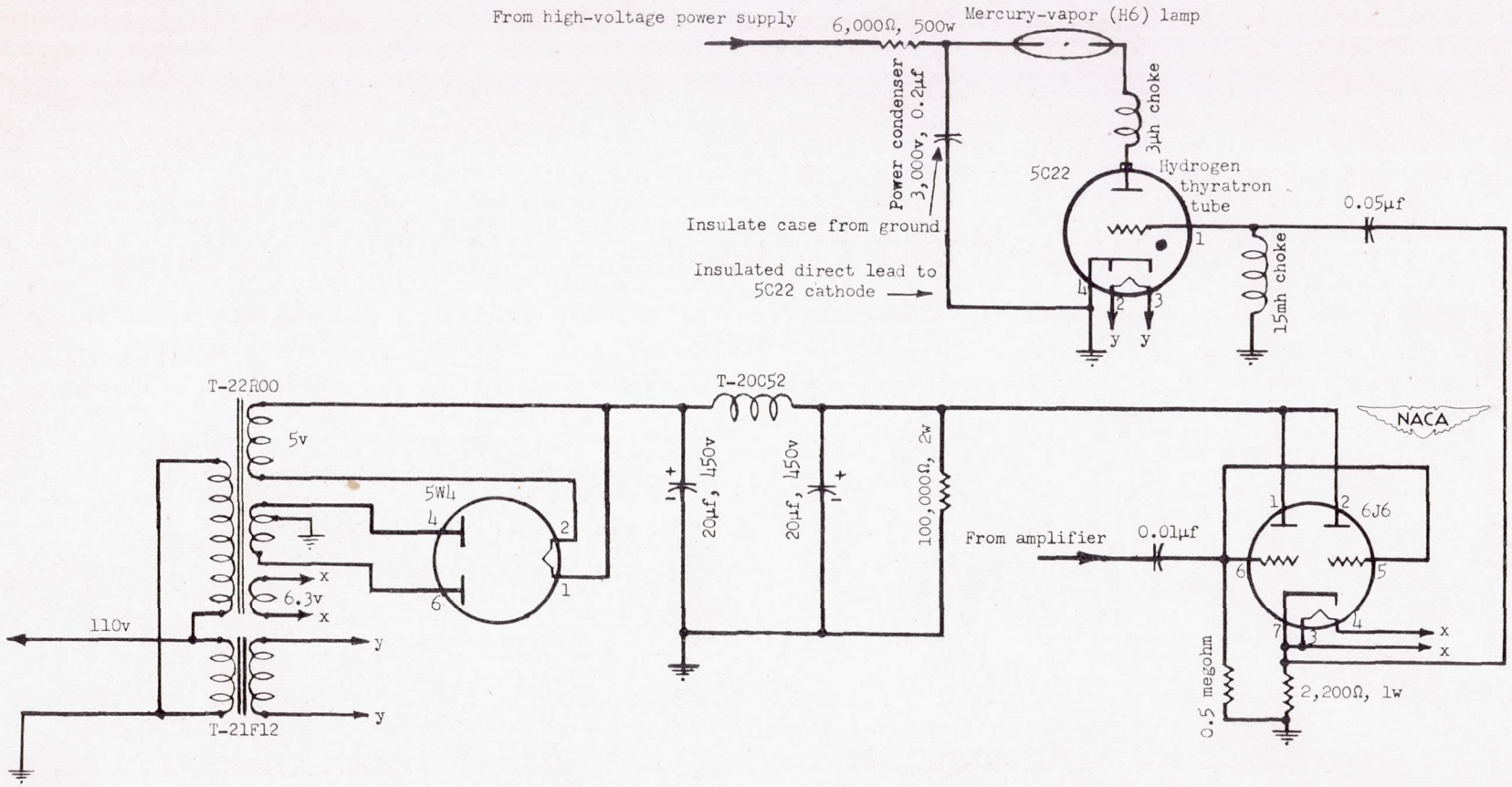


Figure 4.- Modulator.

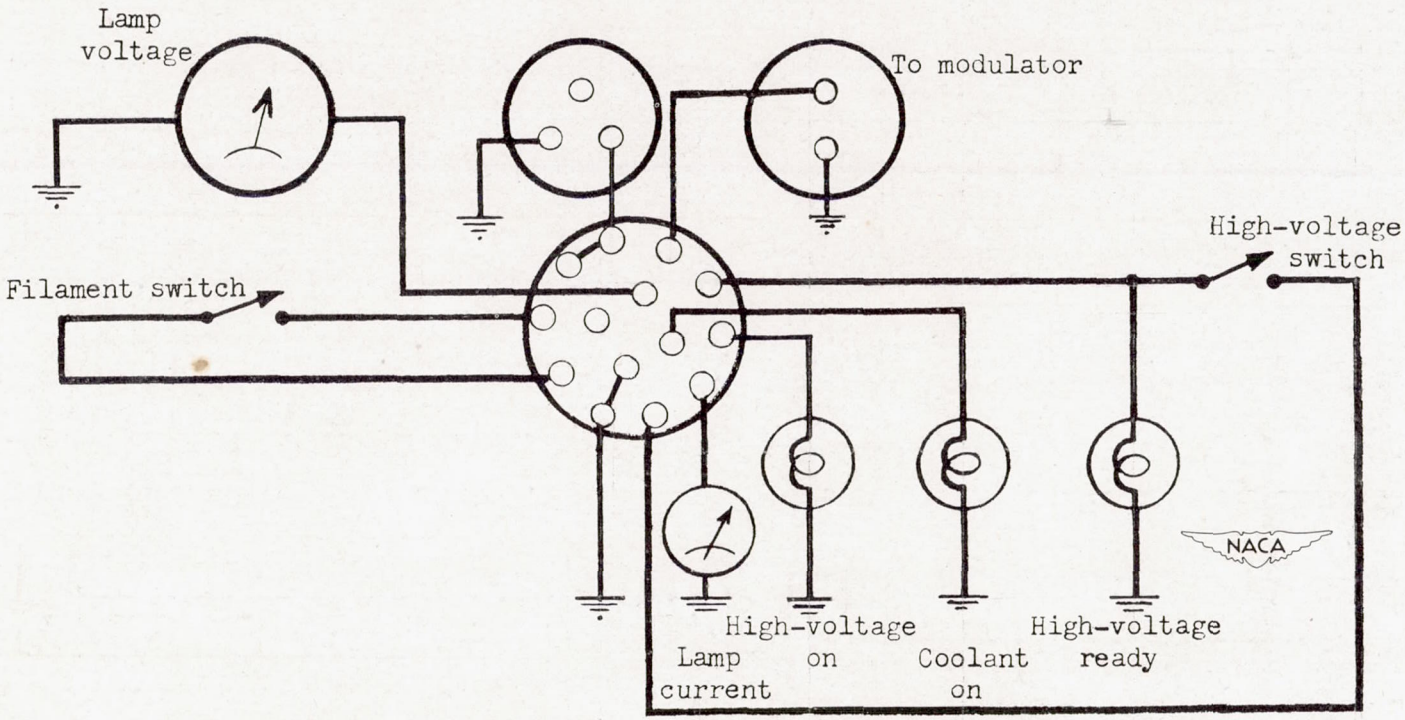


Figure 5.- Control unit.

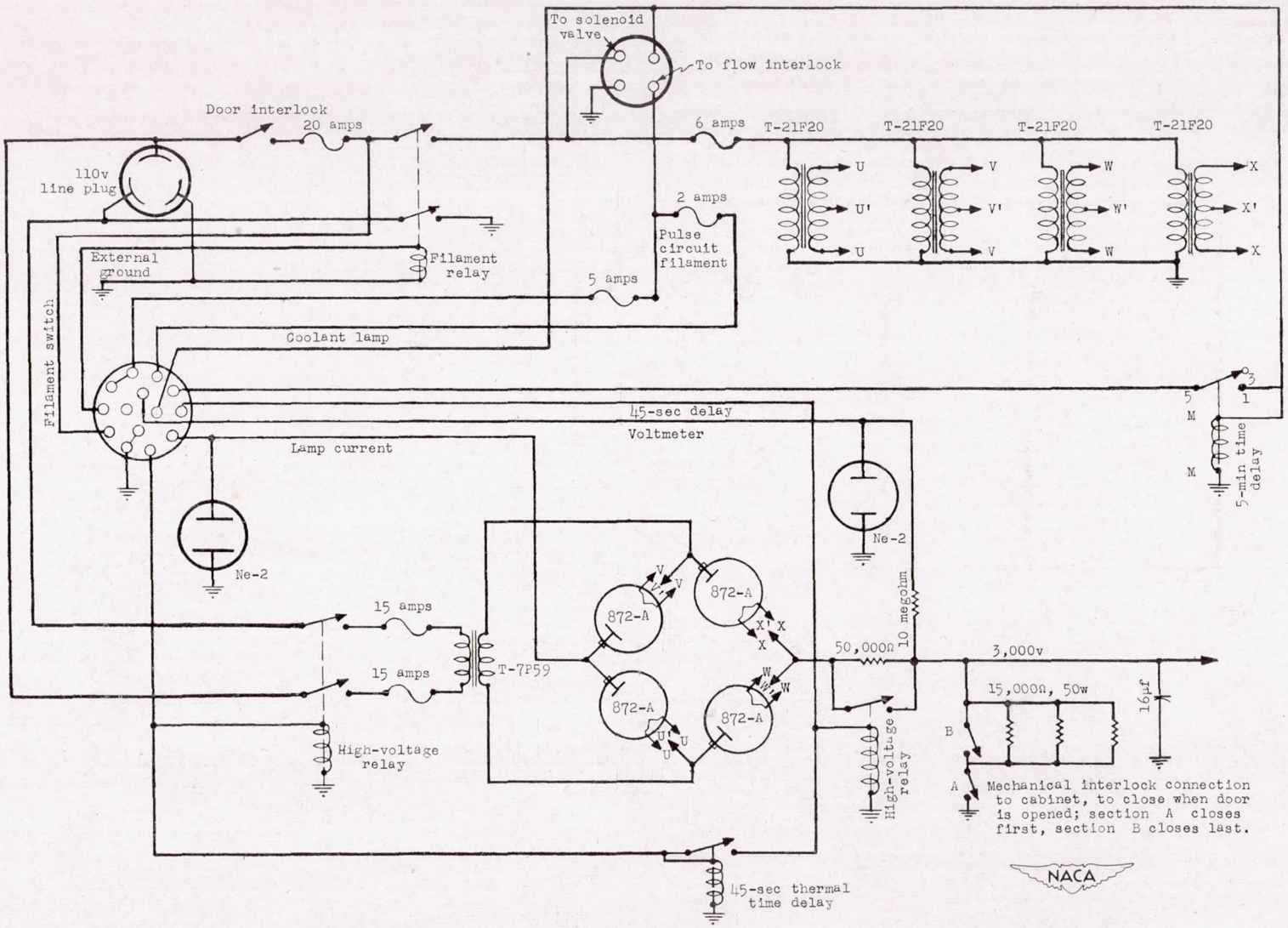


Figure 6.- High-voltage power supply unit.

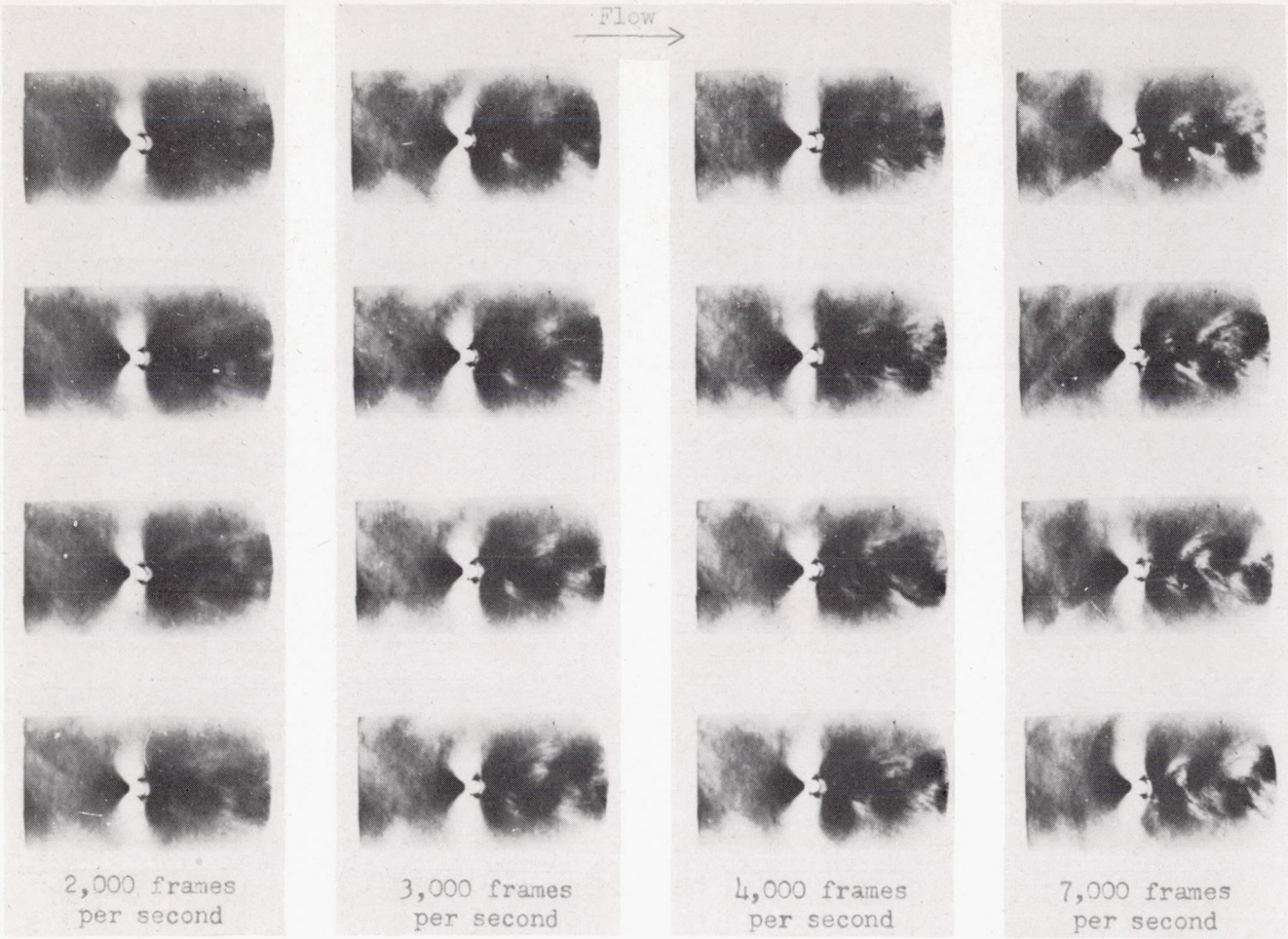


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Figure 7.- Flow photographs obtained by conventional or continuous-light technique.

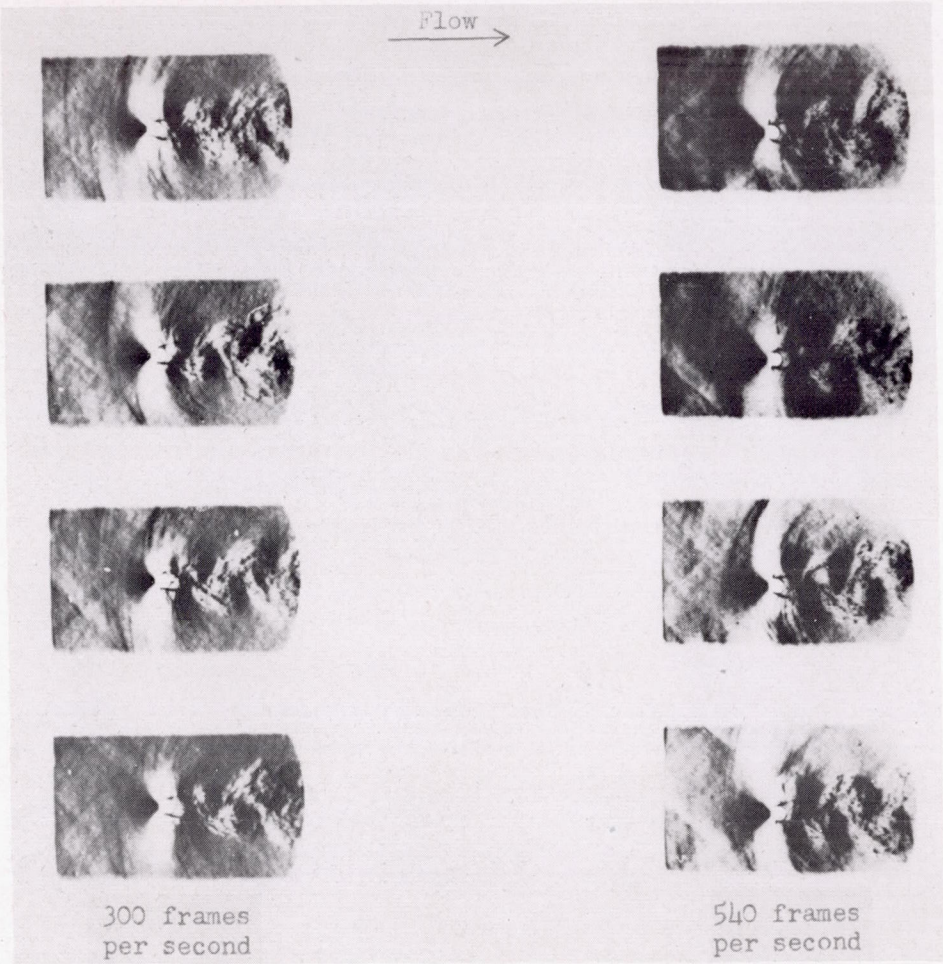


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Figure 8.- Flow photographs obtained by synchronized variable-frequency-light technique.

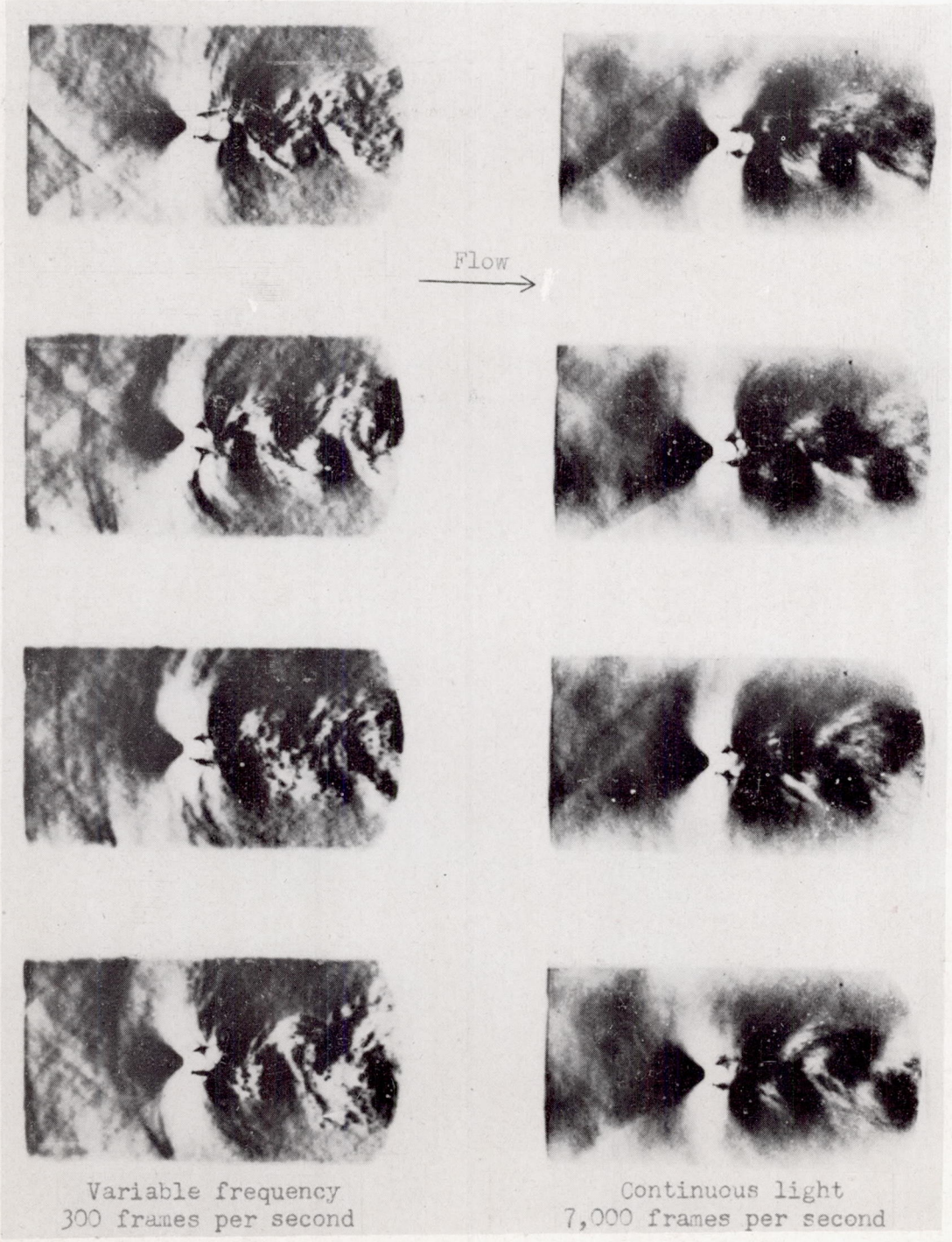


Figure 9.- Comparison of results from the two techniques. L-78191.1

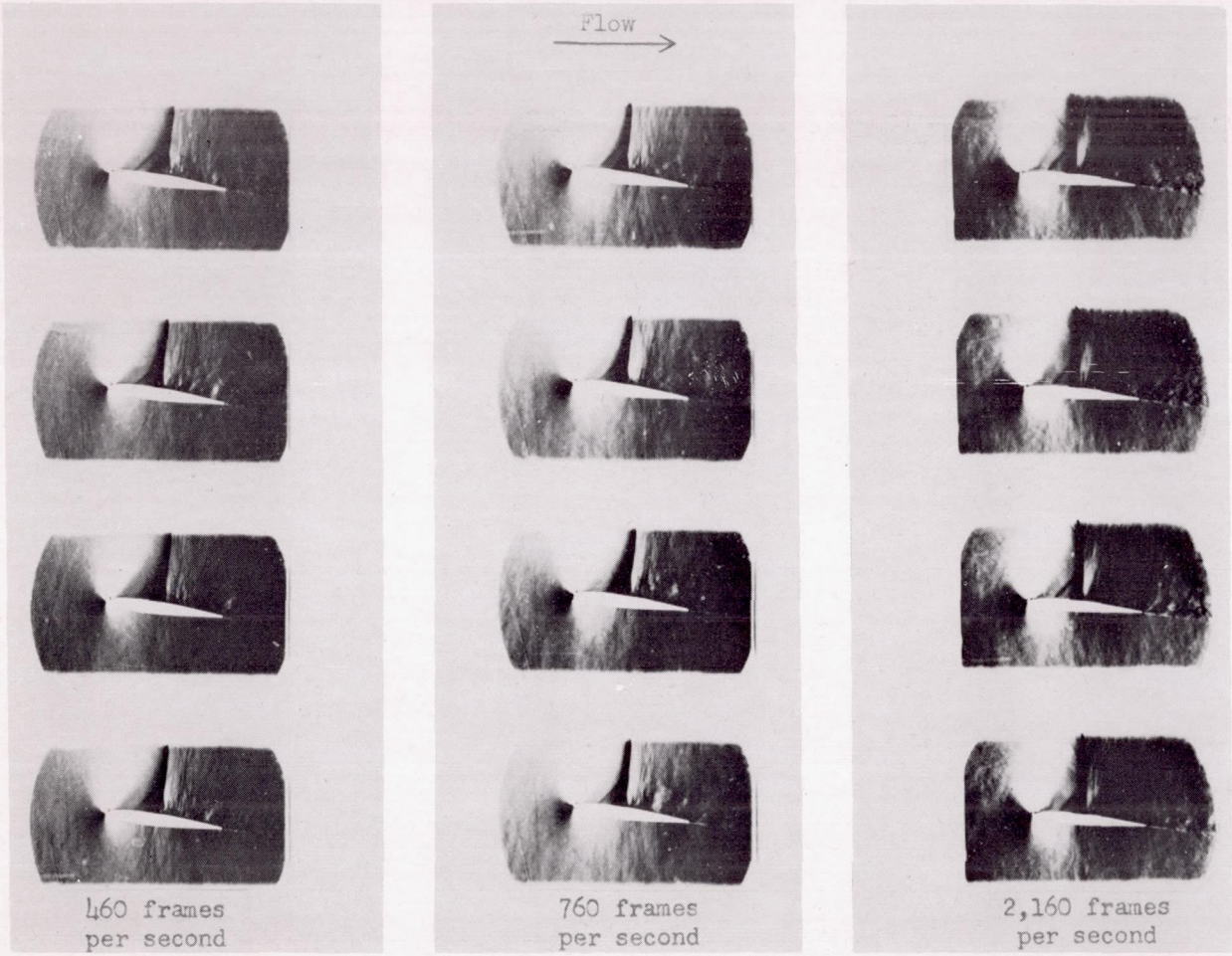


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Figure 10.- Flow past airfoil photographed by synchronized variable-frequency-light technique.



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