How a set of mathematical curves and formulas can be used to convert data derived from the still photograph of a new whirlybird to specifications for its performance in action.

THE CALCULATION OF SOVIET HELICOPTER PERFORMANCE

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The chariness of the Soviets in disclosing facts about their military establishment and the technical characteristics of their equipment extends even to items not used primarily for military purposes. Despite stringent security, however, they are not able to continue concealing a new item once it is in series production and has been issued in quantity to field units. Recognizing this fact, they finally relax to the extent of demonstrating new equipment they have in service at such public affairs as the May Day Parade, attended by all foreign military attachés stationed in Moscow. Or alternatively, a picture of a new item may appear in a Soviet military journal over some such caption as "Another Great Proletarian Achievement" or "The Highest Performance in the World."

The U.S. technical intelligence analyst thus finds before him one or more photographs of some new item of equipment along with a terse Soviet description of it implying that it has successfully passed user tests and may actually be in production. This is of course not enough. Its performance and characteristics must be determined as accurately as possible if its influence on Soviet military capabilities is to be properly gauged. The analyst can prod the field collector with requirements and wait for more information to come in. On the basis of his appreciation of the Soviet state-of-the-art in the new item's field, he can meanwhile make some guess as to what its performance should be. But on many important items he can do much more, and does. By assembling all the available information, obtaining dimensions from an accurate scaling of the photographs, and making certain assumptions if necessary, he proceeds systematically to calculate the probable performance of the new piece of Soviet military equipment. This article shows by way of example how the principles of mathematics and engineering can be applied to estimate the performance of a new Soviet helicopter.

Required Data

The helicopter is a very complex machine, comprising a myriad of moving parts, black boxes, and structural members. Since, however, the principles of helicopter engineering are well understood and the laws of nature apply as inexorably in the USSR as in other parts of the world, it is possible, relying to some extent on U.S. developmental experience, to arrive at a number of significant conclusions about a Soviet helicopter from its outward appearance. The first step is to obtain accurate dimensions by scaling one or more good photographs. Some of the more important dimensions to be obtained are the aircraft's total length, its landing gear dimensions, the diameter of its rotor or rotors, and its rotor blade root chord and tip chord length (the width of the blades at their inner and outer ends). From these dimensions can be derived a number of values which will be needed in subsequent calculations—the area of individual rotor blades, the area of the rotor disc (the whole circle swept by the rotor), the rotor solidity ratio (total blade area divided by disc area), and the cross-section areas of various parts of the aircraft. The outward appearance of the helicopter should also help to establish whether it is powered by a gas turbine or a reciprocating engine and will show whether it has single, twin, coaxial, or tandem rotors.

All information about the aircraft obtained from other sources, overt and covert, is now assembled and recorded in table form. Two important additional specifications needed are engine horsepower (rating for normal continuous operation and for take-off) and the linear speed of rotor blade tips. But if reliable information on these is not available they can usually be estimated: the rotor disc area will usually give an indication of the engine horsepower of a helicopter of given size, and the speed of sound constitutes for the rotor tip speed an upper limit which cannot be approached (even in forward flight) without undesirable air compression and separation effects. The type of rotor and its blade and disc area will also show the gross weight of the aircraft.

Weights and Payload

Having assembled the above information, obtainable with some interpolation from a good photograph, the analyst can now calculate probable performance values. His first computation, in my judgment, should be the weight of the helicopter empty. This he determines by aggregating the weights of its various sections and component parts, specifically the rotor blades, rotor hub assembly, body group, landing gear, engine section, power plant, power plant accessories, rotor mast, transmission drive shaft, transmission, starting system, cooling system, lubrication system, fuel system, instruments, flight control equipment, electrical system, furnishings, and communication equipment. Established mathematical expressions for the weight of each of these components in terms of the specifications determined above have been shown by statistical analysis to yield sufficiently accurate results. For example, the weight of the main transmission for a single overhead rotor powered by a reciprocating engine is 0.081 $\left(464\frac{HP_M\, R}{V_T}\right)^{0.88}$, where HP_M is the take-off horsepower rating of the engine, R is the rotor disc radius, and V_T is the rotor tip speed. Similar expressions have been established for each of the other sections, and the sum of these is the weight of the aircraft empty.

This net weight may now be subtracted from the previously determined gross weight to give a figure for the useful load, comprising the load of fuel, the weight of the crew, and the payload. The fuel weight can be calculated from the range of the helicopter, or if this is unknown it can be assumed at approximately 200 nautical miles, the average range of most modern helicopters. The number of crew members, usually one to three, can be estimated from the size of the aircraft, and each can be taken to weigh with his personal equipment 200 pounds. The useful load less the weight of fuel and crew is the payload, and we have thus obtained our first important performance value.

Ceilings, Speed, and Climb

In order to establish the hover ceiling for the helicopter, the altitude it can maintain without forward flight, it is necessary to plot two curves, power required against altitude and power available against altitude; the altitude at which these curves intersect is the hover ceiling. The power available diminishes with altitude, the gradient of the curve depending on the type of engine in the aircraft. Plotting data can be obtained from any standard propulsion handbook. The power required, on the other hand, increases with altitude. The same factors apply to propulsion forward, and similar curves can be used to obtain the maximum and normal cruising speeds at any given altitude.

The graphs developed for obtaining the hover ceiling and forward speed can also be used for calculating the vertical and maximum rates of climb. The maximum is attained in forward motion because the power required for forward flight is less than that required for hover. The rate of climb is a function of the surplus power available under given operating conditions, and the maximum rate of climb can be expressed mathematically as $33000\eta\left(\frac{ahp}{W}-\frac{Bhp_{MIN}}{W}\right)$, where η is propulsive efficiency, ahp is power available, W is gross weight, and Bhp_{MIN} is the minimum power required for forward flight under any conditions. The rate of climb thus calculated can be used further to establish absolute and service ceilings for the craft. The absolute ceiling is reached when the maximum rate of further climb is zero, and the service ceiling is defined as the point where rate of climb drops to 100 feet per minute. The altitudes at which the available and required levels of power satisfy the equations $33000\eta\left(\frac{ahp}{W}-\frac{Bhp_{MIN}}{W}\right)=0$ and $=100$ are therefore the absolute and service ceilings respectively.

Range and Endurance

There are a number of performance values which depend on fuel consumption rate. These include range (longest one-way flight), radius (round trip with stop), endurance (time in the air), cruising speed for maximum range, and cruising speed for maximum endurance. These values can be obtained from the performance curves already determined plus the SFC/BHP curve (specific fuel consumption *vs* brake horsepower developed) of the engine. Since a SFC/BHP curve for this particular engine is not usually available, a curve typical for its power and type (reciprocating or gas turbine) can be obtained from a propulsion data handbook. This assumption is not likely to lead to any serious error.

The cruise fuel rate in pounds of fuel per pound of gross weight per hour $\left(\frac{dR_F}{dt}\right)$ can now be expressed as a curve plotted against forward speed. The minimum value of $\frac{dR_F}{dt}$ will coincide with the velocity (and corresponding power setting) for maximum endurance; and a tangent to the curve from the point of origin will indicate the velocity and fuel rate for maximum range. If the amount of fuel carried by the aircraft is known or can be determined (e.g., from the size of the fuel tanks), the range and radius can be calculated from these results. Conversely, however, the range of the helicopter can frequently be assumed to be 200 nautical miles and the amount of fuel it must carry can then be determined by reverse process. The radius of a helicopter is usually less than half the range because of fuel consumption in the second warm-up and take-off for the return trip.

There are a number of other performance values which are of considerable importance in estimating the effectiveness of a helicopter in service. Some of these, such as life expectancy of component parts and time required for overhaul, can not be determined by analytical methods, but only by testing the aircraft under field operating conditions. Others, such as stability and control values, can be found by calculation but in my opinion do not warrant the effort required. The fact that the Soviets have decided to mass-produce a given helicopter model is sufficient indication that it responds to its control instruments with reasonable promptness and that it does not suffer from serious aerodynamic instability. Lengthy computations to arrive at these conclusions are hardly necessary.

The principal calculations made in estimating Soviet helicopter performance are therefore those outlined above in very abbreviated summary. The summary outline will have been enough, I hope, to show the reader how, with relatively little to go on, it is possible to arrive at significant conclusions about a new Soviet model. The performance values thus obtained are of course mere approximations, which should accordingly be used only in the absence of more reliable data. As soon as overt or covert collection media can furnish dependable information, the calculated values should be discarded in favor of more accurate figures based on observation or actual tests of the aircraft.