TITLE: Estimating Aircraft Performance

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VOLUME: 6 ISSUE: Winter YEAR: 1962

# STUDIES IN INTELLIGENCE

A collection of articles on the historical, operational, doctrinal, and theoretical aspects of intelligence.

*Ramified process of determining the characteristics of a new model displayed at a Soviet air show.*

# ESTIMATING AIRCRAFT PERFORMANCE

**Isadore Herman**

When the Soviet Union unveils an airplane of new design, as it did in some numbers at its air show last July, the U.S. Air Force has an immediate requirement for an estimate of the machine's performance characteristics in order to assess its place and contribution in the complex of Soviet air power. Such an estimate can be made with good reliability if a few photographs of the plane have been taken from the ground. The task begins with the photogrammetrist and the photo interpreter.

*Drawings to Scale*

The first job—and it is not a simple one—is to transmute the photographs into a three- or six-view drawing properly dimensioned. It is the photogrammetrist who makes the calculations for these drawings. He begins by determining the true shape of the aircraft and the proportion its dimensions bear to each other. Absolute values, the scale of the drawing, can come later. A preliminary step is to get correction factors for any distortion in the photography due to the camera itself. These should be readily available; all attaché cameras are checked and calibrated before being sent out to the field. The proportional drawing then becomes an optics problem to be solved by descriptive geometry and spherical trigonometry.

If a rectangular block is photographed from an angle, the lengths of the three sides on the image do not bear their true proportions to one another and the angles are not right angles. Knowing that the three sides are actually at right angles, however, we can calculate what attitudes the block could have been in to produce this image and what the apparent proportion of the sides to one another would be at various look angles. If we had several photographs of the block from different angles, we could plot each of these look angles as a function of the apparent proportions of the sides in each. The intersection of these lines, since they all refer to the same block, would be the point which defined the true proportion of the sides to one another. (See Figure 1.)

An airplane has some of the geometric regularities of a rectangular block and one of the methods used to find its proportions is similar to this. A line drawn between the two wing tips of any plane must be perpendicular to the center line of the fuselage and the wing tips must be equidistant from this center line. The tail must be perpendicular in the third dimension. By measuring the apparent length, wing span, angle between the line connecting wing tips and the center line, and tail height, the photogrammetrist can determine their true proportions as though they formed a block. Then, using this true ratio of length to span and height to span, he can work the equation backwards for any one photo-

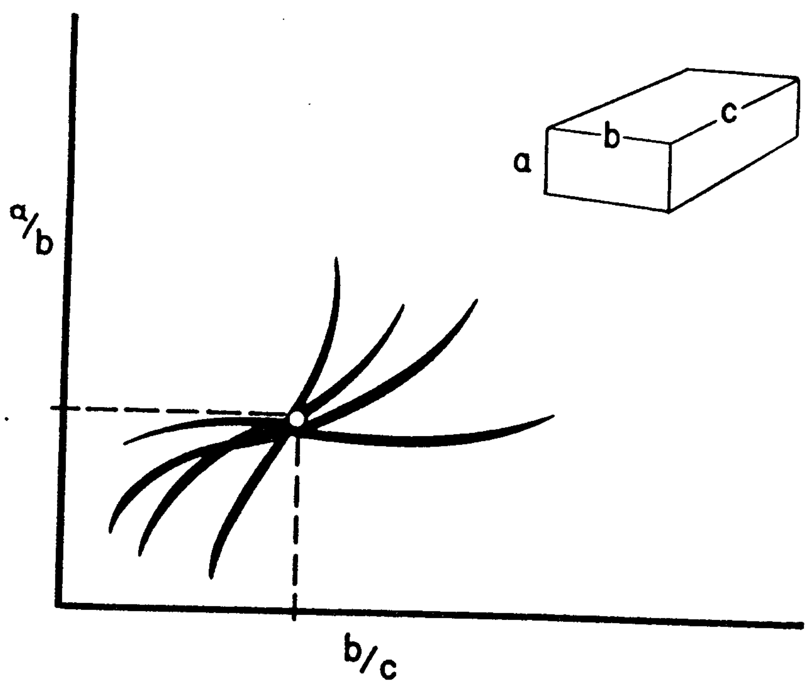


FIGURE 1

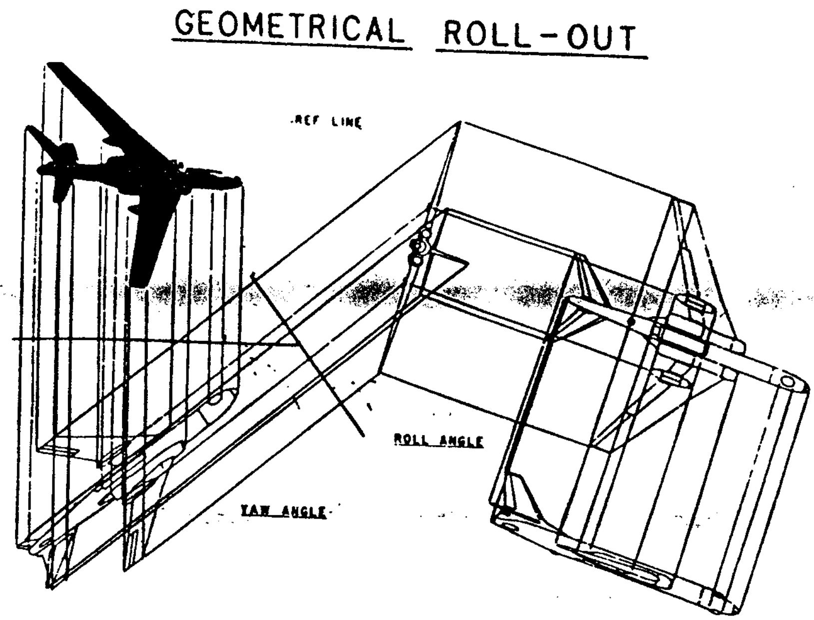


FIGURE 2

graph and calculate what the roll, pitch, and yaw of the airplane had been with respect to the camera plate. (See Figure 2.)

This data is furnished to the photo interpreter, who rectifies the aspect of the photographic image and produces the required three-view proportional drawing. The photo interpreter here really wears two heads. He must use his knowledge as a photo interpreter to find and reproduce visible features of the airplane; but he must also use his ingenuity as an illustrator to fill in the areas that are not seen so that they will be properly portrayed. In reconstructing these unseen areas, there is an important interplay between the photo interpreter and subject analysts expert in aircraft components.

The next problem is that of scaling the drawing, of determining the absolute dimensions of the aircraft. If we know the exact range from which the photograph was taken—most likely if the plane was not in flight—we can calculate the scale directly as the quotient of the camera's focal length by the range.[1] In the absence of this information we must rely either on known aircraft or other objects also in the picture or on features recognized from earlier models—such things as turret blisters, radar domes, and antennae—assuming that they are still the same size. Analysts may have documentary data containing clues to the size of external components, or material in the photo research file may help.

The three-view dimensional drawing is thus completed by personnel of the Foreign Technology Division of the Air Force Systems Command, which has central responsibility for estimating the performance characteristics of the aircraft. Many units of the FTD are involved in the performance estimates—the Aircraft Directorate, the Propulsion Directorate, the Engineering Analysis Directorate, the Electronics Directorate, and the Weapons and Industry Directorate. They include specialists in propulsion, preliminary design structures, aerodynamics, performance, weights, armament, and electronics. These are all represented on a task force assembled for the estimating project. The Aircraft Directorate, in particular, monitors the progress of the analysis. All contributing units are now given copies of the drawing.

*Performance Factors*

The Propulsion Directorate has the task of estimating the power available to the aircraft and the performance of its jet engine. They have from the drawing the exhaust port diameter and an inlet configuration and size. First they try to correlate these with some engine known to be available, but more often than not this is not possible. Then they take whatever background information there is, make some assumptions, and perform several analyses of alternative possibilities for the engine cycle to arrive at an initial estimate. This is a thrust-velocity curve for sea level and one for some altitude such as 35,000 feet. (See Figure 3.)

The weight analyst meanwhile is estimating the take-off gross weight of the airplane and breaking it down into fuel, structure, landing gear, tail, wings, etc. The method is es-

[1] See Kenneth E. Bofrone's "Intelligence Photography" in *Studies* V 2, p. 9 ff.

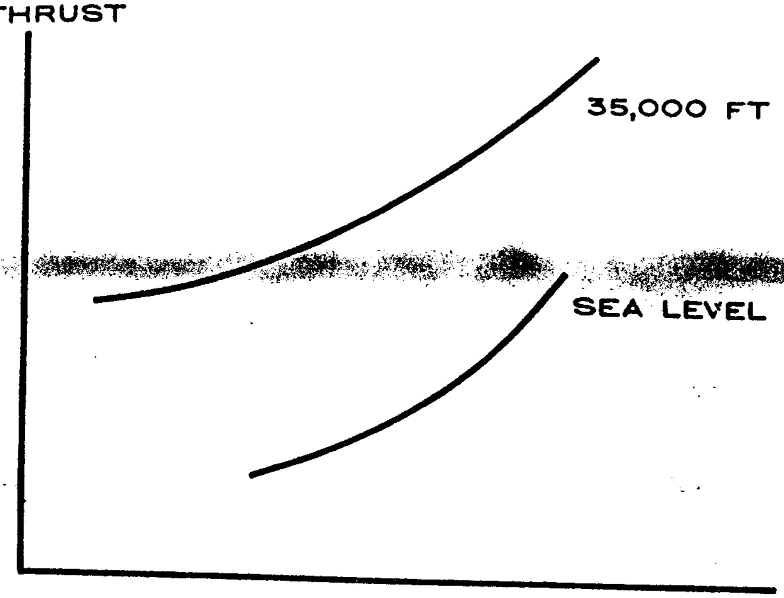


FIGURE 3

sentially the same as that used in industry for preliminary design, approximating the component weights that have been empirically determined to correspond to such-and-such dimensions, volumes, velocities, etc. For example, the weight of a wing is a function of its dimensions, its structural material and design, the speed regime for which it is intended, and the weight of the airplane. The trick, supposing that we can get values for these factors from our photographs, is to formulate the precise relationship among them.[2] Weight engineers have devised complex formulae which vary with the manufacturer, one for an aircraft built by Douglas, for example, and a different one for a Boeing airplane. It is our aim to find the formula that applies in the USSR and ultimately its variations for individual design bureaus in the USSR. In this we still have a long way to go.

[2] For a more specific illustration of this and some of the other methods used in a narrow application of performance analysis, see Theodore A. George's "The Calculation of Soviet Helicopter Performance" in *Studies* III 4, p. 43 ff.

The structures specialist, working from the three-view drawing and any supporting information on such things as rivet lines, determines the structural layout of the airplane. This serves two purposes: it helps production analysts reconstruct how the aircraft was built up and it provides a check by limited stress analysis on whether the structural limits of the airplane are exceeded by the performance estimated. No complete stress analysis is run.

The layout specialist prepares an inboard profile, laying out the equipment, fuel, engines, etc., in the skeleton of the three-view drawing in functionally correct arrangement and providing accommodation for the volume of fuel estimated by the weight analyst. The layout is also used in deriving the weight distribution and balance of the plane.

Armament, electronic, and equipment specialists use the dimensional data of the drawings along with features identified in the photographs to reconstruct the armament, electronic, and other component systems used in the plane. These are not necessarily of importance in determining the performance of the airplane itself, but they are later used by weapons systems analysts when they evaluate its operational effectiveness.

The aerodynamics specialists determine the drag and lift factors affecting the airplane's performance. Drag estimation for supersonic flow is complex, usually including skin friction drag, compressibility drag, wave drag, interference drag, and drag due to lift. Skin friction drag is a function of the area of the aircraft exposed to the airstream (the "wetted" area, in aerodynamic parlance). Compressibility drag is encountered when speed becomes sufficient to compress the air around the forward surfaces; it creates a sharp increase in total drag in the transonic region. Wave drag is a result of pressure distributions unique in supersonic flow. Interference drag is caused by the proximity of one component of the airplane to another; for example, an airplane with external tanks, because of the influence of the pressure distributions from the fuselage and wings on the tanks and vice versa, has a total drag greater than the sum of that for the clean airplane and that for the tanks in isolation. Drag due to lift in supersonic flow is similar to that in subsonic flow, but with an additional component. In supersonic flow the center of pressure is located halfway back along the wings (about 50 percent of wing chord, in technical language) rather than at the forward quarter (25 percent chord) as in subsonic, and there must be a trimming of the aircraft to compensate for this shift in center of pressure. The trim drag thus induced is the additional supersonic component of the drag due to lift.

The foregoing types of drag are only those arising in the external aerodynamics. Another type of drag is considered along with the engine performance problem. Called spillage or additive drag, it results from pressure differences around and just inside the lip of the engine air intake. It is of sufficient magnitude to require inclusion in estimates on supersonic aircraft.

The method of drag estimation used in FTD was chosen from among those used by several aircraft companies after determining which of them was most closely substantiated by wind tunnel and flight tests. But knowledge of high-speed aerodynamics is undergoing continual change as flight speeds go up, and methods of performance estimation are advancing accordingly. These advances are kept under constant study and FTD methods are revised and supplemented to keep them up to date.

In estimating lift, we are handicapped by the fact that exact wing profiles cannot usually be established from photographs. But measurements of thickness, aspect ratio, area dimensions, etc., enable us to select a typical airfoil approximating that of the airplane. Data obtained from the National Aeronautics and Space Administration on similar airfoils can then be used to construct lift coefficients.

### *Mission Performance*

Now having data on weight, balance, stress limits, lift, and drag, we check the power required to fly the airplane through a regime of flight speeds against the initial estimate of engine performance prepared by the Propulsion Directorate. It is a question of deciding whether our reconstructed airplane and engine are compatible in combination or whether we should restudy the engine or the aerodynamics. There are several choices that can be made both in engine parameters and in type of engine. For example, if the tailpipe is large, it could be a high-thrust engine with relatively high specific fuel consumption or it could be a by-pass engine with much less thrust but lower specific fuel consumption. Decisions on such points as these are now made by the Aircraft Directorate project monitors on the basis of all intelligence available regarding the aircraft or the requirements it was designed to satisfy.

Once it has been decided that our engine-airplane combination makes sense, the propulsion specialist prepares detailed thrust and fuel flow curves as a function of velocity at a range of altitudes, and the aerodynamics specialist computes drag and lift coefficients as a function of velocity at these altitudes. These two sets of data, together with that on weight, are then turned over to the mission performance specialists in the Engineering Analysis Directorate.

The mission on which the plane's performance is to be estimated is divided into take-off run, climb to cruising altitude, cruise to combat point, combat, and finally cruise home and landing. Best climb performance for a jet aircraft is defined as that in which it reaches its desired cruising altitude in the minimum of time. In order to determine this for a particular airplane it is necessary to find the forward speed that yields the highest rate of climb at each of the whole range of altitudes, in composite the speed profile necessary for reaching the cruise altitude in the shortest period of time. In most flight-testing activities, this is achieved by what are commonly called "saw-tooth climb tests," in which the airplane is required to fly through an altitude span at various velocities and the speed at which the maximum rate of climb is achieved is then established as best for that altitude and weight.

We do essentially the same thing by calculations, comparing the thrust available with the thrust required for the various altitudes and weight conditions during the climb. When rate of climb is plotted as a function of velocity at a given altitude and weight, the top of the curve represents the speed for best climb and the point at which the curve crosses the axis is the maximum speed for that altitude. (See Figure 4.) To these results there must be applied an acceleration correction to account for velocity changes with altitude; this is taken care of in the computation.

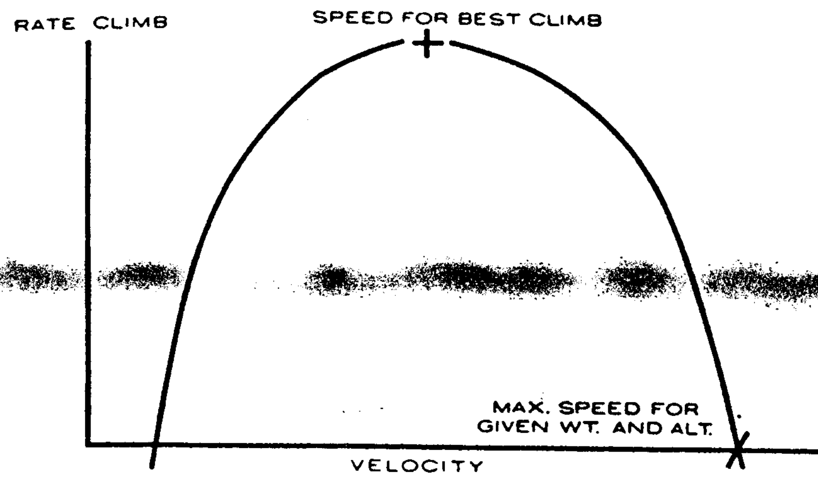


FIGURE 4

The power settings, altitudes, and speeds for cruise are the chief factors in determining the maximum radius or range for the airplane. The rules governing best performance during the cruise portion of the mission are important because the majority of the time in flight, at least for a bomber, is spent in cruise and the largest amount of fuel is used. In accordance with standard military specifications, a constant potential rate of climb is maintained during the cruise for the given weight condition, the variables being altitude and speed. In designing an optimum mission performance, we pick a potential rate of climb that will yield the maximum in nautical miles per pound of fuel. This is not necessarily at the highest altitude, as one might conclude at first glance from the fact that jet engines normally operate most efficiently with respect to fuel consumption at the highest altitudes.

The type of combat and the power setting used therein are important determinants of the amount of fuel consumed during the combat portion of the mission. As throughout the entire mission, the weight of the airplane is important, and we must take into consideration the amount of fuel burned at any point. The weight of the bomb or ammunition also needs to be considered.

There is a great deal of variation in standard requirements for fuel reserves on landing. Normal military specifications call for a 30-minute flying time reserve, but also 5 percent of the initial fuel. If you take off with a 200,000-pound load, this means landing with 10,000 pounds of fuel. Such a reserve seems to us excessive in estimating the radius of a bomber, so we keep fuel for a 30-minute reserve endurance, but do not allow the 5 percent. The 30 minutes are flown at maximum endurance conditions at sea level and the number of engines operating is determined accordingly. For the BISON this meant two engines operating and two dead; when two engines were operated at high power, the specific fuel consumption was lowest and less fuel was required for the 30-minute period.

*Computation*

As must by now be evident, there is a great deal of computation required in preparing a performance estimate. To be more precise, over 250 engineer man-hours used to be expended on the performance estimate for one airplane. With the aid of automatic computers, however, it is now possible to obtain in less than an hour an amount of data that had previously taken about 180 man-hours. There are still 70 or 80 hours of engineering time required, but further research indicates that we may be able to reduce this residue materially.

Roughly similar to this process of aircraft evaluation is missile evaluation; but even for a cruise missile, the mission profile, the type of power plant, and the aerodynamics are slightly different. They are different again in the ballistic missile, where, however, automatic computers are particularly useful in performing the tedious integrations necessary in calculating the trajectory.