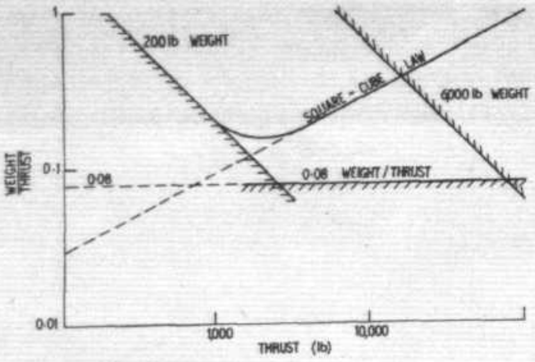


Fig. 3 (left). More limits.

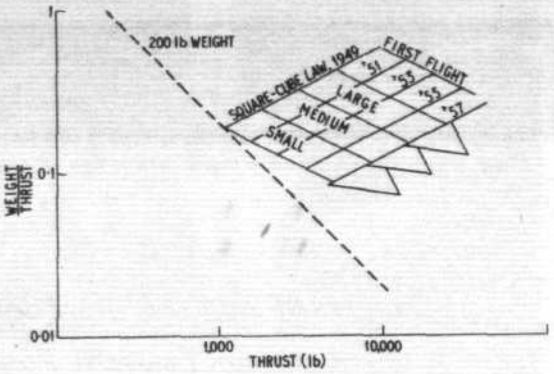


Fig. 4 (right). Direction of development.

BIGGER AND BETTER TURBOJETS . . .

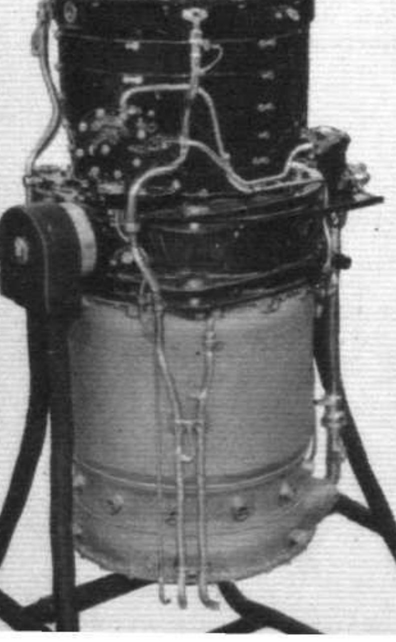
borough,† to find out what is the true value of this "best" size. As one might perhaps expect, it always turned out to be the size the calculator had already decided to build, thus merely confirming that he was doing the best he knew how. Finally, when the Soar was made available for sale in the States, it became clear to everyone there that 2,000 lb thrust was just right, and no less than a dozen U.S. engine builders offered to develop such engines for the Air Force. So far, neither of the two engines which won this competition—Fairchild's J83 and General Electric's J85—has flown, and the market even for these is looking a lot thinner than it did four years ago.

Two other limit lines can be applied to the field of the "square-cube law." First, an upper limit can be set to the weight of a single turbojet that any aircraft builder may be willing to use. This line is drawn in Fig. 3 as 6,000 lb, though the exact value is not important. Next: whatever the optimists may believe, there must be an absolute limit somewhere to the improvement that can be squeezed from the turbojet formula. In Fig. 3 an again arbitrary value of 0.08 is shown as the lowest weight/thrust ratio that will ever be attained. The square-cube line has now been considerably hedged in, and we pass to the most important factor of all: time.

The Time Factor. The usual development of a successful series of engines follows a ten-year course, with the first flight made after 3 years, acceptance for production aircraft after 5 years, and the first flight of a growth version (with up to 50 per cent more power) after 6 years. Major technical development of a given series normally ends after ten years, and most attempts to prolong development life beyond this have not succeeded. Of course, production may continue for very much longer.

The important point to note here is that development of an engine normally involves increases in both power and weight, but with the power increasing twice as rapidly as the weight. (The physical reason for this is that it is much easier to "beef up" parts that fail, than to pare down all those that don't.) Thus, a broad front of development can be drawn, as in Fig. 4, to cover the fields generally thought of as Large, Medium, and Small turbojets.

Across this front, "square-cube law" lines can be drawn, representing the state of the art at any given time, and showing, incidentally, the improvements in weight/thrust ratio that can be achieved by down-scaling an engine. On Fig. 4, such lines are drawn for the years 1949, 1951, 1953, 1955, 1957—on which engines made their first flights. All British turbojets built during the past ten years fit these lines quite closely; others are mostly about two years behind.



Shown here as an exhibition model, the Rolls-Royce R.B.108 can be trunnion-mounted and used to provide vertical thrust. Five are in the S.C.1.

Turbojets of the Future. A discussion of the kind presented here is not of much interest unless it yields some positive predictions. In a very interesting article on the difficulties surrounding technical prediction (*Flight*, March 15 and 29, 1957), Mr. A. V. Cleaver gave would-be prophets a three-part warning:—

(1) "It is highly dangerous to make negative predictions," especially in describing ideas as "wholly visionary," or "of no commercial value."

(2) "Long-term journalistic predictions" frequently turn out to be more reliable than those of "soberly skilled experts."

(3) "Allowances should always be made for . . . new developments, even when these cannot be foreseen in detail."

It is hard to disagree with these propositions in general, but they do not provide much help. The fallacy in the second is that for every "journalistic" prediction which turns out to be nearly correct hundreds of quite different results have been foretold by forgotten scribblers. Mr. Cleaver quoted with glee the undue caution of Nevil Shute and others: he might have included a paragraph written by a man who is frequently hailed today as the father of science-journalism and future-writing. Listen to H. G. Wells in 1902 on the "coming invention of flying":—

> "I do not think it at all probable that aeronautics will ever come into play as a serious modification of transport and communication. . . . Man is not, for example, an albatross, but a land biped, with a considerable disposition to being made sick and giddy by unusual motions."

It appears to the present writer, however, that any dangers facing prophets today are more likely to be those of over-optimism and complacency. Every schoolchild knows for sure that in a few years' time he will travel to work by flying armchair, there to converse in binary notation. Spare weekends will be spent on gay round-trip cruises to Proxima Centauri. Few people are anxious now to point out the limitations to our capabilities, for, as Mr. Cleaver emphasized, this is the least rewarding task.

Like Man himself, all of our creations have their phases of early growth, maturity and saturation—when they are replaced by the next most promising device. A plot of the classic growth curve to a logarithmic scale (Fig. 5) shows the period of exponential growth very strongly, and it is this line which is generally extrapolated to indicate the direction of progress. But attempts to predict the saturation limits for any one type of device are always desirable, if only to show what kind of new developments will be of most value.

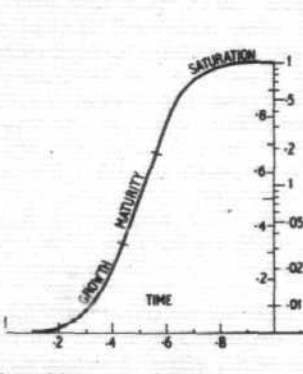


Fig. 5a. Linear scale of progress.

Fig. 5b. Logarithmic scale.

With this justification, some forecasts are set down about the development of turbojet engines. Future State of the Art lines can be drawn on Fig. 4, and subjected to limits such as those shown in Fig. 3. The following conclusions appear:—

(1) The "square-cube law" relating engine thrust and weight applies only to a given State of the Art, and takes no account of progress in design techniques. It always over-estimates the saving in weight obtained by clustering engines.

(2) Present-day *small* turbojet engines are certainly very light, but neither their development potential nor long-term market are substantial. They should reach their thrust limit of 4,000 lb in a year or two.

The best weight/thrust ratios ever likely to be achieved in turbojet engines will be not from clusters of beercan-size engines, but from large single engines of 50,000 lb thrust, which fly in ten years' time. If this proposition appears unacceptable, it is worth recalling that a similar situation already holds for both piston engines and ramjets.

(3) The present series of *Large* turbojets will soon complete its course, with engines around 35,000 lb thrust (sea-level static), and weighing close to 6,000 lb. These should make their first flight in 1959.

(4) The long-term development of turbopets lies chiefly in the direction now pointed by the unrelated series: Viper, Orpheus, Gyron Junior. These future *Medium*-size engines will use techniques of both the present-day *Large* and *Small* types, to yield, by the middle 1960s, the ultimate series of turbojets with thrust between 20,000 and 50,000 lb, and weighing less than one-tenth of their thrust.

(5) Though active development of such super-turbojets will cease before 1970, the engines will be used for many years beyond this, for take-off and landing of rocket-powered aircraft of all sizes, as well as for the more prosaic job of driving VTOL inter-city buses.

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†See, for example, the lecture presented by Alan Pennington to the Anglo-American Aeronautical Conference in 1951.