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High performance power plants

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as guest

Development of a two-stroke motor for a ML-power plant (Motor-Luftstrahltriebwerk – hybrid piston motor driven jet engine)

By Wunibald Kamm

Concerning aerodynamic configuration for power plant cowlings

By Theodor Zobel

Dissertation
Held during the 5th scientific conference of the
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High performance power plants

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By Helmut Schelp

A. Introduction

All lines of thoughts, considerations, and analysis to increase flight performance, or to say in a more generalised way, to achieve air superiority, leads ultimately to placing special attention on power plants for aircraft and missiles. Herein, there exists a certain interaction, which on the other hand only allows a starting point from the present know-how of power plants to be able to continuously create better aircraft.

A key prominence goes to research and development that addresses the subject matter of power plants. The awareness of this demands a certain amount of fortitude, to see far into the future in order to perceive the ultimate goal and to plot a clear path for achieving this goal.

During this process of research and development, it is necessary to establish way-points from time-to-time, for assessing the data thus far obtained and to incorporate the results into the overall effort.

Currently, there are three major constituents acknowledged, which outline this state-of-the-art technology.

The piston engine

This group encompasses the entire first part of aviation history, from the very beginning, which used a modified automobile motor, up to today's severe demands on flight performances, which can only be increased further uneconomically or with an unjustifiably great effort.

Jet engine

This second realm of aircraft power plants must be the solution to all subsonic aeronautics. It is the field of application for the jet engine.

Page 4 The limits of flight performance with this type of power plant may be defined with the following specifications:

Speed : Critical speed[1]
Altitude : Up to 20 km
Range : Up to 15,000 km

The Rocket engine

The main utilization of rocket engines as power plants for aircraft will be for supersonic speeds at very great heights. Since this third realm of technological development is yet inaccessible, no set goals of its limitations may be set. However, one must take into consideration that the questions of engine development may be easier to answer than the questions of aerodynamics and flight mechanics.

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[1] Critical speed means supersonic speed

B. The Piston Engine

In review of the current state of development of the piston engine, it is recognisable that no further ground-breaking improvements may be visualized. It is clear from the latest round of strategy for enhancement of this type of engine that the limits for this power plant have been reached. It is necessary to shift the major emphasis for research and development to the jet engine.

In such a cornerstone of technological development of power plants, which may be viewed to be equal to a revolution, it is necessary to review the past developments to identify a trend of advancement.

In view of the growing demands for increasing flight performances, it was necessary to build more powerful engines. In addition to improvements of combustion and the use of better fuels, it was possible to increase cylinder performances, and thus power plants were built with increased numbers of cylinders. With the growing understanding of engine thermodynamics and the internal workings of the power plants, it was possible to decrease fuel consumption and the weight of the engine at the same time. The demands for more power was made possible by increasing intake air pressure by the use of mechanical superchargers or exhaust turbochargers.

Since time is an important factor during an engine development phase, liquid cooled engines were given priority, but without neglecting the air cooled motor. Page 5 Germany is fifteen years behind in experience with air-cooled engine development, and the goal could be reached more quickly if the question of cooling could be answered on a parallel basis. Wide-ranging knowledge of air cooling was not yet adequate enough to allow an understanding where the limitations are to be set in regard to power out-put and obtainable altitude.

This procedure was needed to guarantee a smooth development process for the individual aircraft manufacturers. It is self-evident that constructional elements of established and proven components should be used whenever possible, especially in regard to existing aircraft types. Even the decision to choose a different form of engine for an existing type of plane may have significant consequences.

The whole technical development phase may be characterised by the following aspects:

1. Piston engines were developed.
2. They were rated by horsepower for the crankshaft power out-put, by fuel consumption per hp, weight per hp.

Such engines were thus, as the need dictated, incorporated into engine nacelles of the aircraft to complete their development into aircraft power plants.

The fundamental concepts of the engine builders, which built and designed motors with this basic knowledge, were irrefutable as long as actual requirements were met.

When reaching higher air speeds, were the high velocity air-stream nears the speed of sound, specific aspects become evident that demand detailed studies.

This situation has been recognized in time by the appropriate authorities in Germany. In retrospect, the newly laid-out and innovative engine development program, initiated by the RLM in 1938, must give the entire power plant research a new face.

It had become imperative to be aware that the approach of properly recognized solutions is to be accomplished in a step-by-step manner. The posed requirements could be answered only if the problems with the gas turbines are solved, whereby it was known that such a solution is not to be accomplished by stationary engine building with its low requirements. With this awareness, no conclusive solution was sought with the construction of the first jet engines; they were merely to provide a base of knowledge and experience for all future engine development.

Page 6 Ever since the first results from the development of the turbojet power plants became available, the time has come to rethink the entire basis of this research and development phase, and to place it entirely upon a new foundation.

C. The Turbojet Power Plant

For the initial stage of the next development phase, the following objectives for performances will be stipulated:

Speed = Supersonic
Altitude = About 20 km
Range = Up to 15,000 km

It should be noted that the desired air speed is not meant to be an ultimately demanded rigid factor, but rather that the maximum air speed should be reached independent to the altitude. The theoretical formulation and resolution of the posed tasks, means to carry out a tactical analysis of the possibilities that technology possesses. As another consequence is the fact that there are no absolute demands for altitude anymore. Altitude alone is no guarantee to stay out of reach from enemy attacks. By use of common power plants, which share similar levels of technology, the defending aircraft will always be in an advantageous position. This will be especially true when rocket engines are available for the defending aircraft.

It is necessary to define the term air stream power plant more closely:

All engines, which take in the surrounding air of the atmosphere to provide the necessary oxygen for the combustion of fuel, may be termed as an air stream engine.

With this definition, normal piston engines could be in this category, whereas the air stream is generated by the propeller. This type of engine, however, shall not be defined as an air stream power plant, since such an engine, which uses pistons for producing power, would have to be developed under far different criteria.

Page 7 **I. Comparisons and performance values**

Fundamental contemplation proved that the established task could not be further solved through continued development and improvement. Hence, it became obvious that the problems must be reviewed from the ground up, since applying the previously established principles could falsify the groundwork from the outset.

In the past, power plants were considered as something unchangeable. One was content to know that this particular crankshaft power out-put was available for a given airframe. This viewpoint was correct to this point as long as the power plant did not offer any resistance in its own self, is incorporated fully inside the airframe, and does not offer any additional resistance as such. This is possible only in very few cases, for instance when rocket engines are installed in an airframe. It becomes ever more difficult to have an engine incorporated fully enough with increased air speed. Normally, the engines will be mounted on the wings, in which case the ensuing air resistance cannot be neglected. Thought should be given that the coefficient of resistance of the airframe must be found by an experimentally established value.

High air speeds, up to the supersonic range, are possible only if specific reducible factors are examined more closely and everything possible done to diminish them further.

The airframe air resistance as a whole may be subdivided into,

$$W = W_{\text{airframe}} + W_{\text{power plant}} + W_{\text{interference}}$$

The power plant resistance $W_{power\ plant}$ is the air resistance of the engine nacelle while exposed in the slipstream.

The interference resistance is the value which results when the engine nacelle is mounted in the airframe.

The power plant thrust index during a constant, level flight is:

$$\begin{aligned} S_i &= W_{aircraft} \\ &= W_{airframe} + W_{power\ plant} + W_{interference} \\ S_i --- W_{power\ plant} &= W_{airframe} + W_{interference} \end{aligned}$$

Due to the lack of test facilities, it is not possible to find the interference resistance. It may be ascertained mathematically from the other values.

Page 8 In the future, it will be necessary for the engine builder to be concerned with more than merely shaft power out-put, but should include the following:

$$S_i - W_{power\ plant} = S_e$$

The effective thrust, S_e, is the thrust that is available to the aircraft after the engine's own air resistance has been excluded.

$S_e = S_i - W_T$

S_i = indexed thrust in kp
W_T = air resistance of power plant in kp

Generally, the value for indexed thrust:

$S_i = m\,(c - v)$

m = inducted air mass per second in kg m – 1 sec.
c = exhaust velocity in m/sec.
v = air speed in m/sec.

Propeller driven aircraft have the following values:

$$\begin{aligned} S_i &= S_L + S_v \\ &= m_L\,(c_L - v) + (c_v - v) \end{aligned}$$

S_L = propeller thrust in kp
S_v = exhaust gasses thrust in kp
m_L = air mass taken-in by the propeller in kg m – sec.
c_L = velocity of air mass behind the propeller in m/sec.
m_v = air mass ingested by the engine in kg m – 1 sec.
c_v = exhaust gas velocity in m/sec.

it is,

$S = Nx75/v \quad N = S\,v/75$

thereby,

$S_L = n_{schr}\; N_w\, 75/v = m_L\,(c_L - v)$

n_{schr} = propeller efficiency
N_w = crankshaft performance in hp

$S_v = N_v\, 75/v = m_v\,(c_v - v)$

so,

$S_i = n_{schr}\ N_w\ 75/v + N_v\ 75/v$

Page 9 Another characteristic attribute for an engine is its fuel consumption in relation to its effective thrust, S_e. It is defined as kg/kp h,

b_e = kg/kp h

and analogous to the fuel consumption, obtained from the thrust index,

b_i = kg/kp h

For evaluating an engine and for deciding which power plant is to be preferred, its weight will be the only decisive criteria.

The weight of the power plant is the sum of the power plant and the fuel consumption for the required length of flight.

The usual fixed values up- to-date by which power plants were evaluated, such as the calculated crankshaft power out-put, fuel consumption, and weight pertaining to the crankshaft performance, are not decisive for an engine's applicableness. Engines, which possess the same usual fixed values, may differ strongly from one another in relation to the actual important values S_e and b_e.

This divergence has not been very profound thus far, since only piston engines have been used whose comparative values for similar power plants remained valid when used in non-extreme air speeds. The air speeds currently possible demand clarification of the correlativity since serious mistakes will be unavoidable, and, which may be worse, guide the entire effort into a wrong direction.

To be able to display the fixed values of a power plant in a non-dimensional fashion, dependency on co-efficiency of aerodynamics is to be introduced.

$S_e = c_e\, q\, F;\quad c_I = S_i/q\, F$ c_i = indexed thrust coefficient
$S_i = c_i\, q\, F;\quad c_e = S_e/q\, F$ c_e = effective thrust coefficient
$W_t = cwt\ p\ F;\ c_{WT} = W_T/q\, F$ c_{WT} = coefficient of air resistance of the power plant
$c_e = c_i - c_{WT}$ F = maximum frontal area in m^2

Page 10 For the reference size of the frontal area the largest one was chosen since a definite value can be given, and for the best aerodynamic shape of the engine nacelle, which must be a prerequisite from now on, it should be viewed as a characteristic value.

The following would be valid:

$b_e/b_i = c_i/c_e = 1 + cWT/\ c_e$

or,

$b_e\ c_e = b_i\ c_i$

Furthermore, the weight of the propulsion system is a decisive factor for an engine's suitability.

$G_A = G_T = B_T$ G_A = weight of the propulsion system in kg
G_T = weight of power plant in kg
B = hourly fuel consumption in kg/h
t = length of flight time in h

If g_e is designated as the weight of the power plant for 1kp of effective thrust, then,

$g_e = G_{T/} S_e$

and the specific weight of the propulsion system,

$g_A = g_e + b_e t$.

The basic working knowledge as specified above, which are not only decisive for the assessment of a power plant but should also be viewed as a guideline for development, shall be the foundation for the following examination for power plants that are used in all speed categories. It must be mentioned, however, that due to today’s level of know-how it is not possible to provide exhaustive specifications for power plants in every situation, since in most cases the necessary data are not available, whereas those that are available have been made possible only through experimentation. The intention is accomplished when basic considerations are utilized and when knowledge gaps are pointed out, since in many cases having a correct assignment of tasks will lead to success.

Page 11 To get a general idea, comparisons are given of a piston engine – a Jumo 222 C/D with a TK 9, a turboprop power plant – BMW 028, and a turbojet power plant – BMW 018. In addition, the just recently available turbojet power plant, Jumo 004 C, this shall be viewed as a preliminary solution for this type of power plant.

There are not enough figures available to acquire the initial values for cWT and level of propeller efficiency during the various flight conditions that may be encountered. To get an initial value for cWT, a coefficient value from an ideal solid form with low drag was used, whereby the true values are much greater.

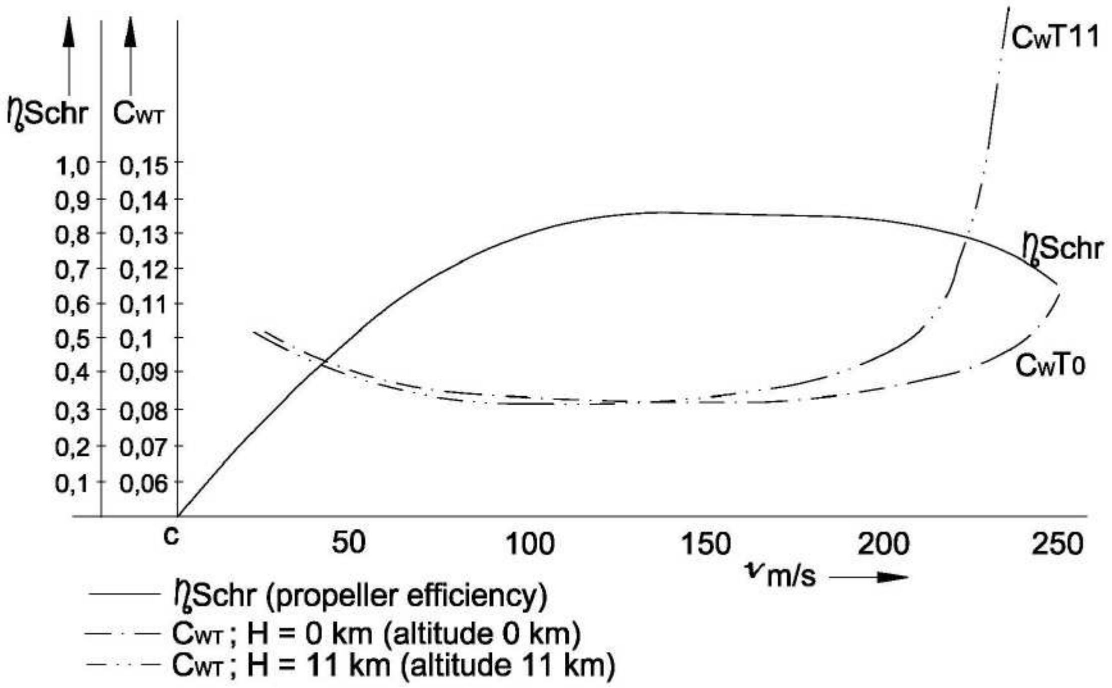

Fig. 1

Fundamental analysis for acquiring the values for cWT and n_{schr}

Figure 1 gives the fundamental analysis for the initial values.

Figure 2 lists the thrust values for the specific power plants. For particular air speeds and altitudes, the c-value is a benchmark for thrust burden of the frontal area of the power plant. The graphic curve, depending on air speed, is proportional for the dependent thrust of the air speed and shows the potentially available acceleration during different air speeds. If the graph line “c” were horizontal the thrust would increase at the same rate as the air resistance, thus the over dimensioning by itself would be decisive for the potential acceleration of the aircraft.

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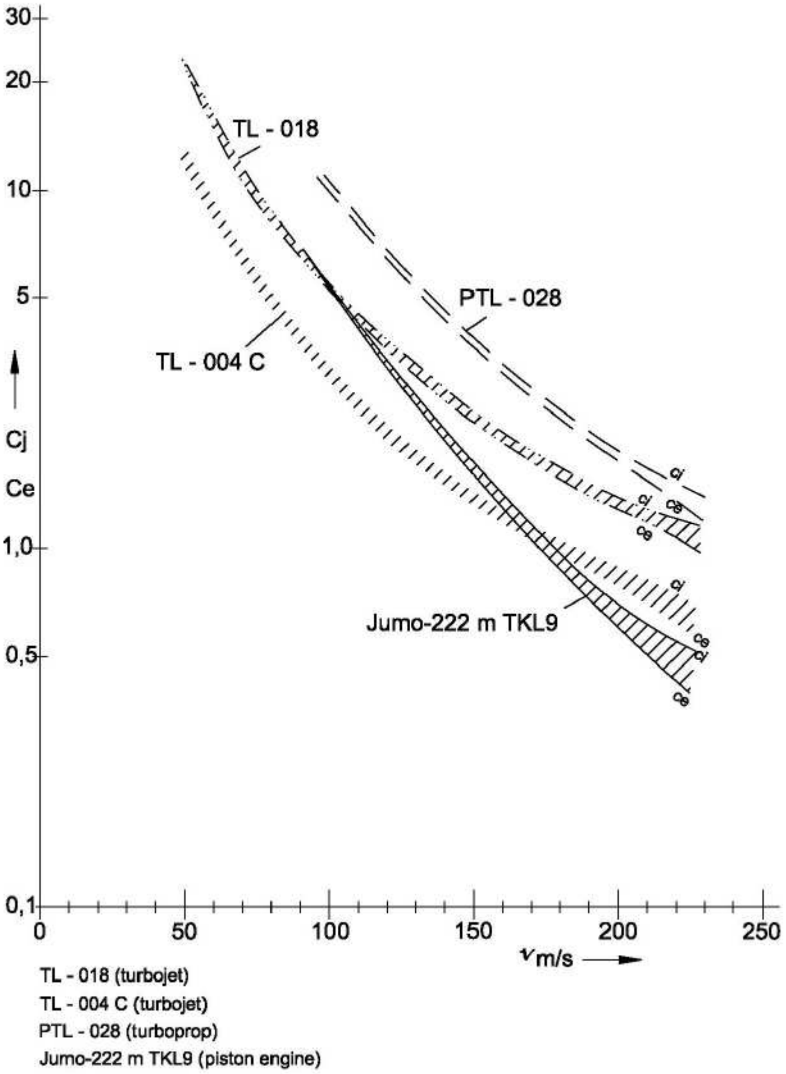

Fig. 2
Thrust values for specific power plants

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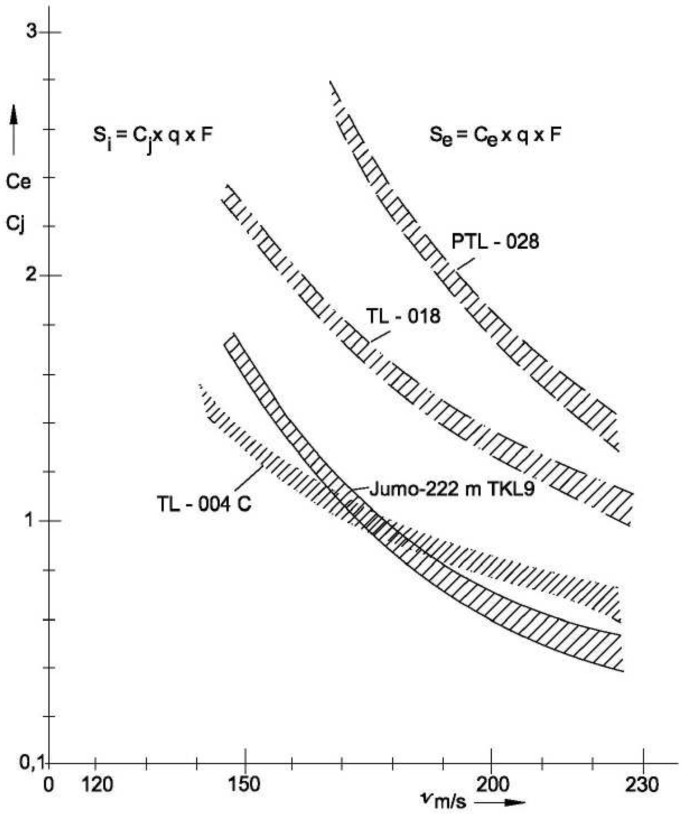

Fig. 3
Thrust coefficients for specific power plants

Figure 3 shows the same values during elevated air speeds with a linear scale. This illustrates very clearly the influence of the airframe's drag. The motor and, to a lesser extent, Page 14 the turboprop, display a very rapid drop-off of the "c" line due to the reduction of the propeller efficiency during high air speeds. The value c_e of the engine is practically zero during these most favorable conditions at a speed of around 235 m/sec. (846 km/h). The power thus produced is negated through the inherent drag. This fact alone illustrates the unfeasibility of piston engines at high air speeds. In truth, this critical point lies in far lower air speeds, since the correct cWT value of the power plant is higher than the minimal value that this diagram illustrates.

In Comparison, the difference to the turbojet can be clearly seen, and when the second development phase is reached, such as with the TL-018 (BMW), it will be even greater. At 220 m/sec. (792 km/h) the c_e value of the TL-018 is about 3 ½ as great as that of a piston engine's. The turboprop's lies even higher, however, the propeller efficiency proves to be an element of uncertainty. Tractor propellers, for instance, display a certain amount of interference drag that cannot be ascertained. To attempt an assessment by simply utilizing theoretical values should be avoided. Other factors play important roles, such as the question of starts, throttle performance, and effects upon to the airframe. The diagram shall merely provide better data than what is now available without being too comprehensive.

Figure 4 shows fuel consumption, b_e, independent of air speed. Up to date, it was common to believe the false notion that turbojet engines have much greater fuel consumption than piston engines. The consumption rate that is of concern, b_e, at 230 m/sec (828 km/h) with the TL-018, is the same as the piston engine and lower than the same at higher air speeds, however, the piston engine has a consumption rate of 220 gr/PSh[2] that corresponds with the

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[2] Grams per horsepower and hour

standard specifications that have been used. Undoubtedly, one can clearly see that the currently used characteristics, made use of in actual assessments, are of no use.

An empirical worth says that a good piston engine possesses a specific weight of about 0,8 kg/PSh. Figure 5 shows different values. The weight is 8 kg for 1 kp effective thrust at 230 m/sec, whereas it is only 1,8 kg for the TL-018.

In the beginning, it had been mentioned that the only factor of measure for a power plant is the weight. The actual operative range is shown in figure 6. The illustration is valid for the important altitude of 11 km. At yet greater heights the disadvantages for the piston engines become even greater.

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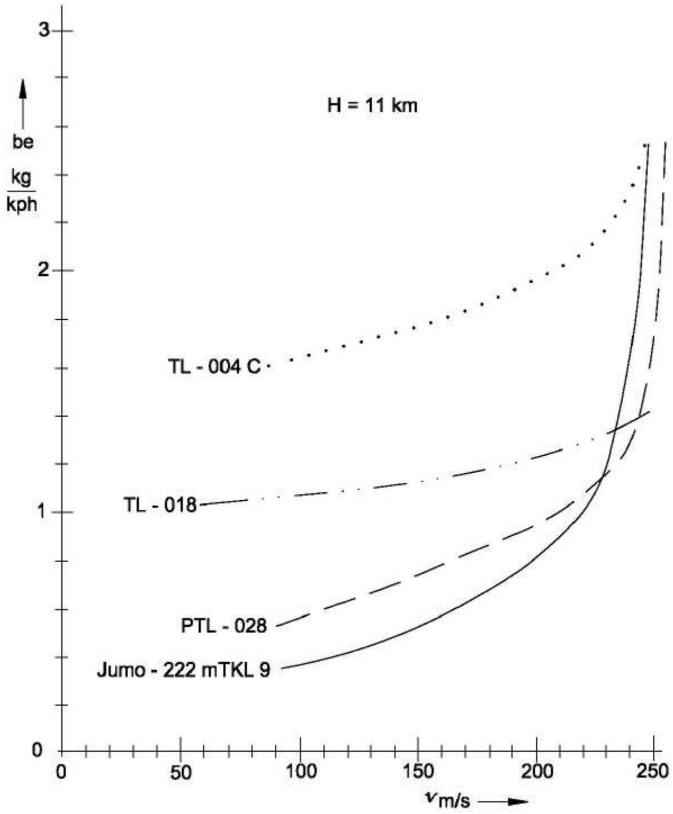

Fig. 4
Rate of fuel consumption for various types of power plants

This diagram shows the fuel consumption for specific engines under the prerequisite that they have the same weight. If one observes the upper part of the lines, at the 11 km level, it is obvious that the piston engine’s advantage in fuel consumption becomes inconsequential

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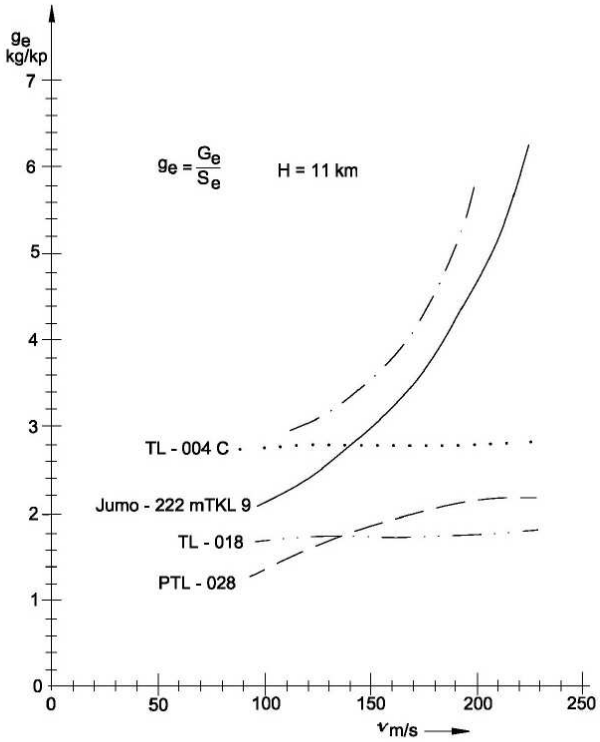

Fig. 5
Power to weight ratios for specific engines

when a range of 5000 km and air speeds higher than 634 km/h are reached. The values given change if the drag interferences are added in the diagram. The forthcoming work group must clarify these conditions in more detail.

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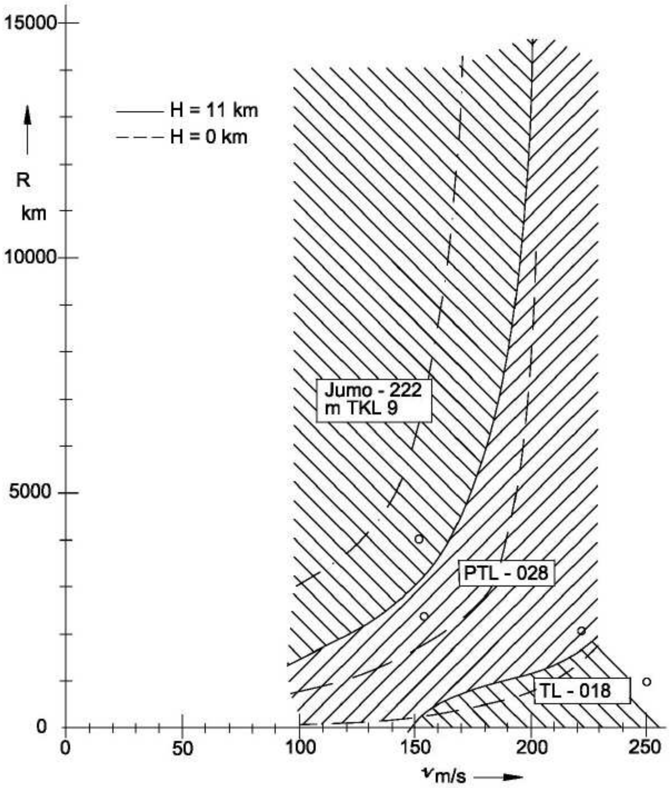

Fig. 6

It is clearly visible that medium fighters, powered by piston engines, cannot achieve the necessary performances with an acceptable effort at the required air speeds that range from 700 to 800 km/h, since range is limited at present level of know-how.

Page 18 For single engined fighters, the stipulated air speeds lie between 850 and 900 km/h. This is the dominating range for the turbojet power plant, since the piston engine cannot deliver this sort of performance.

The dashed lines illustrate that other factors come into play near ground level. The corresponding borderline between piston engine and turbojet are near the higher air speeds. At ground level the ranges are shorter due to the denser air.

The disadvantages for piston engines at great heights become even more extreme due to the increase of air resistance of the engine cooling system and the profound decrease of propeller efficiency. Extreme altitudes will be realized only by use of turbojet engines.

The scope of use for piston engines will be a good deal lower than is the case with turbojet and turboprop engines, since the cWT value will be much higher due to necessary equipment such as oil cooler inlets, diverse other air inlets, exhaust pipes. There is a dash-dotted line in figure 6, which shows the quantity when the cWT value is double as much as the one shown on figure 1 and when the propeller efficiency is 5% less, in effect, 0,82 instead of 0,87 at an altitude of 11 km.

Furthermore, it is to be observed that propeller driven aircraft will have higher drag interference than turbojet driven aircraft.

Only recently are useable research results available for the assessment of piston engine, turbojet, and turboprop power plants. The diagrams illustrate where it is necessary to increase research and development efforts. It will not be possible to reach extreme cruising ranges with any of the three types of power plants. The demanded and available fuel consumption rates for long-range power plants will provide considerable enhancement in potential use.

II. The Propeller Motor Jet (PML)

It had already been pointed-out that the limits of piston engines have been reached with today's available know-how. However, this does not necessarily mean the end to engines employing the piston/crankshaft system. As far as can be foreseen, compared with the turbojet, the weightiness of the piston engine will remain.

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The entire problem of propulsion with engines concerning altitude and air speed should be reviewed by taking the previously indicated characteristic attributes under consideration for evaluation.

Initial considerations of power plants should be made concerning tactical areas of application for ground attack aircraft, fighter bombers, observation planes, for close air support, and for transport aircraft with maximum air speed between 500 and 700 km/h. For such uses a good throttle response at low air speeds is important.

Piston engines best fit into these required performance characteristics. The fundamental task to develop a turbojet, and not a piston engine, cannot be overlooked considering the required utilization. The scope of work demands a maximum for c_i and cWT values, taking into account the compulsory maximum c_e values for the specific flight requirements.

Air Drag For Power Plant Nacelle

First, it is necessary to eliminate any and all aerodynamic disturbances on the nacelle, so as to improve the cWT value. It will be possible to achieve building the best aerodynamic coefficient engine nacelle with this means.

It is worth to strive for an even more aerodynamic nacelle. The air, together with the exhaust blast, must exit the engine with the least possible drag, to achieve as close as possible a level of air resistance that is composed mostly of air-to-surface friction. The main effort will be to minimize the aspect ratio of the frontal area.

The newly established task assignment based on piston engines is:

> A turbofan engine powered by a piston motor that is to be used for specific purposes and displays the favourable values for c_e, b_e, and g_A.

The questions that will emerge with a given example, and are of importance to solving the task, will be scrutinized more closely.

Page 20 Figure 7 shows an example for such a power plant. It illustrates that this power plant differs from a turboprop only through the use of an internal combustion piston engine as a source of power, instead of a gas turbine. It is of no import if the propeller and compressor are being powered fully or partially by a piston engine, or fully or partially by a turbine, to produce the necessary thrust.

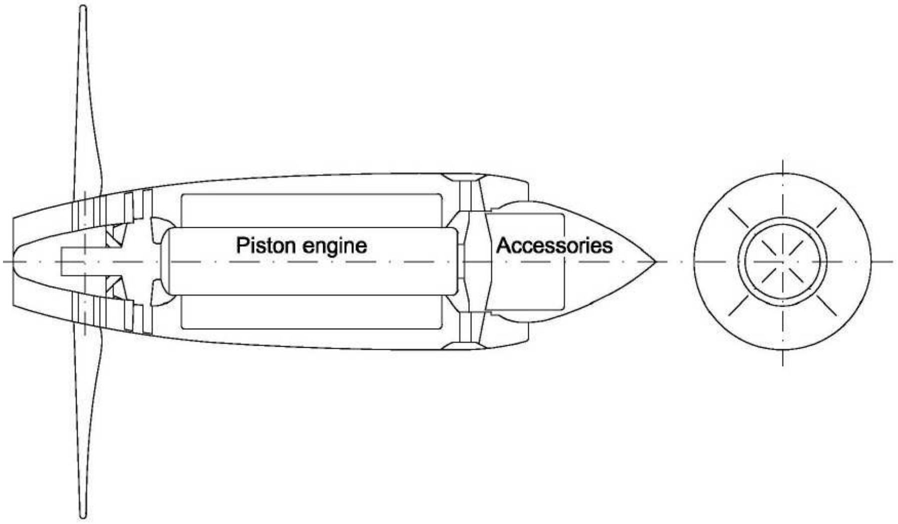

Fig. 7

The required air speed is a point-of-origin for the prerequisite for the distribution of thrust by the propeller and thrust by the jet of air. To clarify this issue, it is necessary to determine this at the conception of the project, whereas not only the efficiency of the jet stream or the efficiency of the propeller is the sole deciding factor. It must also be considered how much combustion efficiency will be used to produce air speed and shaft power out-put. The compressor and turbine cannot be viewed separately, but must be taken into consideration together with the piston engine assembly group.

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The Drive Motor

The drive motor will strongly influence the outer contours of the nacelle. It will be the nacelle designers' job to attain a contour for the nacelle with the lowest drag, so as to obtain the most slender form and shape.

Structural Form

It will be necessary to take a fundamental look at every possible structural form, without being influenced by any sort of dogma.

1. Piston Engine

Due to the most extensive experience with the internal combustion engine, it is possible to make excellent assessments for this power plant for making fairly accurate forecasts. However, such motors have fundamentally different requirements than those in common use in aircraft today.

The best results will be achieved by the use of two-stroke engines with short strokes and capable of very high rpms and that can be put through very high thermal stresses. Concerning the required proposal, this seems plausible due to the very high volume of air that is available.

It is possible to achieve extensive internal cylinder cooling, whereas significant proposals for air-piston cooling are now available.

Since the hot air and exhaust heat produce partial thrust in the mid-range pressure stream of the turbine and exhaust blast, fuel consumption rate per hp for the engine is of no consequence, because the important b_e value may be influenced by other factors.

To my knowledge, suggestions for such a power plant was first made by M.A. Müller (member of the Junkers branch factory in Magdeburg), and was examined by the FKFS (Forschungsinstituts für Kraftfahrwesen und Fahrzeugmotoren Stuttgart – Research institute for motor vehicles and aircraft motors Stuttgart).

Due to the experiences that had been made with turbojet engines, it has been determined that the piston engine powered jet engine is inconsequential for high air speeds, since turbojet engines provide better performances for those speeds and for flight duration.

The most promising air speed range for a PML power plant lies between 500 and 700 km/h and at lower altitudes. For use at those types of air speeds the propeller as a propulsion system cannot be ignored.

Page 22 For the intended purpose, the drive motor will boast a performance level of between 1500 to 3000 hp, and it is probable that a sort of air-cooled inline radial (an “X” engine) will be preferred, which has four rows of 4 to 6 cylinders.

The performance of the engine will have to be fine-tuned to the required altitudes. If it is necessary to have a constant power level at a particular altitude, it may be possible to consider putting in one or more guide baffles for the axial compressor, which will rotate with the impeller at low to medium altitude levels. These will function as superchargers only when high intake pressure is needed in the prerequisite altitudes. It must be examined to see if such a system will provide an advantageous partitioning of thrust between the jet of air and propeller, which adjusts according to air speed.

2. Wobble-plate Engine

The wobble-plate engine should be taken under close scrutiny to find the prerequisite requirements as a drive motor for a PML power plant. This motor’s small frontal-area-to power-ratio seems to be suitable for the intended use. It is not easily resolved, however, to see if an air-cooled version could be used. A water-cooled variety may bring with it difficulties for the mounting of the radiator, if it must lie along the axis of the power plant assembly.

Another advantage such an engine may have, is the possibility to change its compression-ratio, which would increase the power and decrease fuel consumption rate at higher altitudes.

3. Linear “Crankshaftless” Piston Engine

The linkage problems with the wobble-plate engine could not be entirely resolved thus far. With the prerequisite undertaking at hand it is not absolutely necessary to produce shaft power. The motor may be constructed so as to be used merely to produce gas, and it is also not required for the wobble-plate to rotate, but only to wobble, which would mean that the linkage problems would be resolved straight away.

This type of solution suggests that the linear piston engine, possessing no crankshaft and having the required high pressure combustion chamber, should be taken under closer study.

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III Explosion Gas Turbine (pulse-jet)

The preceding discussed options and possibilities for the PML power plant permit the explosion gas turbine to be included as a potential choice.

Considerations should be made to see if the path of the PML power plant should be taken at all, or if the explosion gas turbine should be the ultimate goal.

Presently, no conclusive evaluations can be made concerning this type of power plant, since the problems to be solved are strongly influenced by the theoretical understanding of non-steady state gas dynamics, and it is necessary to continue close studies in this field of knowledge with the explosive gas jet pipe as a foundation.

D. Conclusion

In summary, it may be said that the first great segment of development for aircraft power plants is coming to a close. This is characterised by the use of aircraft engines, which had power out-put, fuel consumption rates, and weight applied as distinctive features for evaluation.

The second great scope of flight performance, which is the present area of interest, is the region of application that is made possible by the turbojet power plant. Early 1939 is the inauguration for this period of development.

It would be beyond the scope of this presentation if all types of turbojet power plants, including all their characteristic features, were to be discussed separately. The diagrams are to illustrate the perspective approach by which high performance power plants should be evaluated and provide a foundation for future planning. Even a quick review shows that only turbojets may be perceived as high performance power plants, which are categorised by the term *air jet* power plant. A comparison is always relative, and only because of the fact that technological advances of turbojets are achievable, it is not justifiable to consider the present power plants as high out-put engines.

However, it is an undeniable fact that the difficulties in studying this matter will grow until the necessary base of knowledge is available. It is not said often Page 24 enough that the required research is still lacking severely. It is only due to war-time conditions that such a rapid rate of development in certain areas had been made possible, whereas it is clearly seen that all still-to-be answered questions must be resolved through research, since serious mistakes may otherwise be made.

Beyond that, it is necessary to lay-out a clear path for future development so as to make possible a clear and concise course for the tasks at hand.

For this reason, the three four-year time-periods that were foreseen for accomplishing the postulated requirements are re-examined.

1. The first developmental phase counts as the one which provided the necessary

fundamentals and allowed the turbojet to be brought to maturity without having it initially produce extreme power out-puts.
This segment is concluded and has brought forth revolutionary results for the entire field of power plants, and not only for the Luftwaffe.

2. The task for the second phase is as follows:
   TL-Triebwerk (Turbojets) with higher out-put ratings
   (improved power plants with differing out-put ratings, high altitude flight)
   ZTL-Triebwerk (Turbofan)
   PTL-Triebwerk (Turboprop)
   Gleichdruck-Strahlrohr (Impulse Turbine)
   Tasks for pre-development and research:
   GTW (Gas turbine with heat exchanger, long-range power plant)
   PML (propeller motor jet)
   Verpuffungsturbine (pulse-jet)

3. The third phase is to find solutions in developing the gas turbine engine with heat exchanger for long-range flight.

   Due to new-found knowledge for the piston engine as power unit for the PML, it must achieve favorable performance.

   Furthermore, it is desired to find developmental solutions for the gas turbines, based on previous experience with explosion gas turbine (pulse jet).

Page 25 The major development is thus ended for the time being. This phase shall, along with improvements of the available power plants, bring forth solutions to the airframe for long range flight.

R = 15,000 km
v = about 600 km/h
H = 6 to 9 km

Furthermore, the development of the PML power plant must bring about a change of fundamental engine use for transport planes and close combat aircraft.

It is difficult to predict the future. But sometimes it is necessary to drive on with all the specific details on a broad basis so as to come to a comprehensive conclusion. Even when an intended plan sometimes gets accelerated, hampered, or even cancelled, alone the fact that a problem has been recognized in time, success may thus still be achieved.

An appointed program cannot be given for supersonic flight within the third major phase, since a basis for requirements are not yet available for the start of the development. As far as the power plants are concerned, this is no problem. Before a start can be given, more research must be accomplished. In time, this problem will also be addressed so that all research sectors involved will have a fundamental ground to stand on.

Symposium

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Triebnigg: What we just heard are extraordinarily interesting statements. Your clear presentation illustrates in an ostensible way the developmental possibilities that individual types of power plants today posses and in the future.

Neugebauer: When thoughts are given over future aircraft power plant development, one question stands out very soon, which actually should be desired to be solved in the first place, but whose handling lets one recognize shortly that one will stumble upon problems when attempting its solution, and that question is: Which type of power plant is best suited for a specified flight requirement? Herr Schelp dealt with this element elaborately during his presentation; here, I'd like to show how to perhaps place this understanding upon a more solid foundation.

Generally, our power plants have the intake air compressed in a couple of steps, first by ram air and then by supercharger – in effect an air stream machine – and then a motor – a piston engine. Then the charge is burned, which expands up to a certain pressure inside the piston engine, then in a turbine and finally in a thrust nozzle. Well, theoretically one could indiscriminately draw a line of division between these compression steps or the expansion steps, and one could leave away whole machine groups, for example the piston engine or the turbine. How does one best select a choice?

To come closer to an answer to this question, I'd like to reflect upon a suggestion that stems from Herr Günter and which was brought to my attention by Herr Helmbold. Günter theoretically breaks-down an aircraft into a utility vehicle, which carries only the cargo, and a tow aircraft, which carries only its engine and fuel; he calculates the required thrust that the tow-rope needs and ascertains the engines' applicability. I'd like to go one step further and theoretically separate the power plant and fuel from the airframe of the tow aircraft. The correlation of the available thrust is:

$$S = V - R_u - R_m$$

The forward motion, V, is the result of thrust, produced by the propeller and thrust nozzle. The immediate resistance, R_u, is from the engine nacelle and the cooling system, and the collateral resistance, R_m, is from the towing airframe.

Well, it is desired to achieve required thrust with the least amount of expense. Generally, we've got into the habit to consider this "expense" solely as fuel consumption; one should go one step further and include the expense the power plant and towing airframe cause. These expenditures contain the cost of manufacture, maintenance, overhauling based on serviceable life span, and all this is difficult to ascertain.

We can now establish a figure of value:

$$n = S \times W/A$$

Page 28 S = net thrust, W = distance flown, A = expense. When analysing the equation, one sees a relationship between altitude, air speed, length of flight, propeller efficiency, weight of the power plant, fuel consumption rate, internal set-up of the power plant (for instance the breakdown of the pressure-drop), weight of the airframe, cost, and life-span of the engine and airframe, etc. One sees that the relationships are not easy, however, one should not be dismayed but begin to gather the necessary data in order to obtain a rough solution; a rough solution it is, naturally, because due to the drifting nature of this state of technology, which demands constant corrections.

I can imagine a diagram, which illustrates in its ordinates the perimeters of different power plants suitable for prerequisite altitude, air-speed, and flight duration. With the help of this diagram it would be possible to ascertain the most appropriate type of power plant for a given application.

The task is being worked on by several work groups including the DVL (Deutsche Versuchsanstalt für Luftfahrt – German Research Institute for Aeronautics), which is supporting me in a thankworthy manner, and I hope that in time to achieve a fairly accurate solution, which will save us certain time consuming and painstaking development effort and choosing an optimum balance by providing a guideline from the onset.

Günter: I have been concerned with the comparison of different types of power plants for a longer period of time now, and have also used a similar relationship of power plant weight that is based on net power out-put. I have found, however, that this depiction fails to illustrate enough the characteristics of the whole aircraft. To be able to judge an aircraft's potential performance, different types of operational stresses should be used to illustrate the performance in diverse flight altitudes. In addition to the engine characteristics, the reachable performances are also, naturally, reliant on the allowable expense for the power plant = power plant weight/gross aircraft weight. Propulsion weight = power plant + fuel + fuel tanks. By a constant weight of the airframe, this expression also gives the specific effort of construction = operating weight/gross payload weight.

Since the surface area of aircraft wings are dependant on the plane's weight, and the median speed and range dependant on the aircraft median weight, it would be better to use median aircraft weight in the equation instead of gross take-off weight.

$$\frac{\text{median propulsion weight}}{\text{median operating weight}} = \frac{G_{Am}}{G_m} \quad \begin{array}{l}\text{(antriebsgewicht)} \\ \\ \text{(fluggewicht)}\end{array}$$

For a given G_{Am} / G_m there are a variety of aircraft viable, depending if more is expended for operating weight of the power plant (fighter) or more for the fuel. Therefor the figure below has the quantity,

$$\frac{\text{median operating weight}}{\text{standing thrust}} = \frac{G_m}{S_o}$$

to use.

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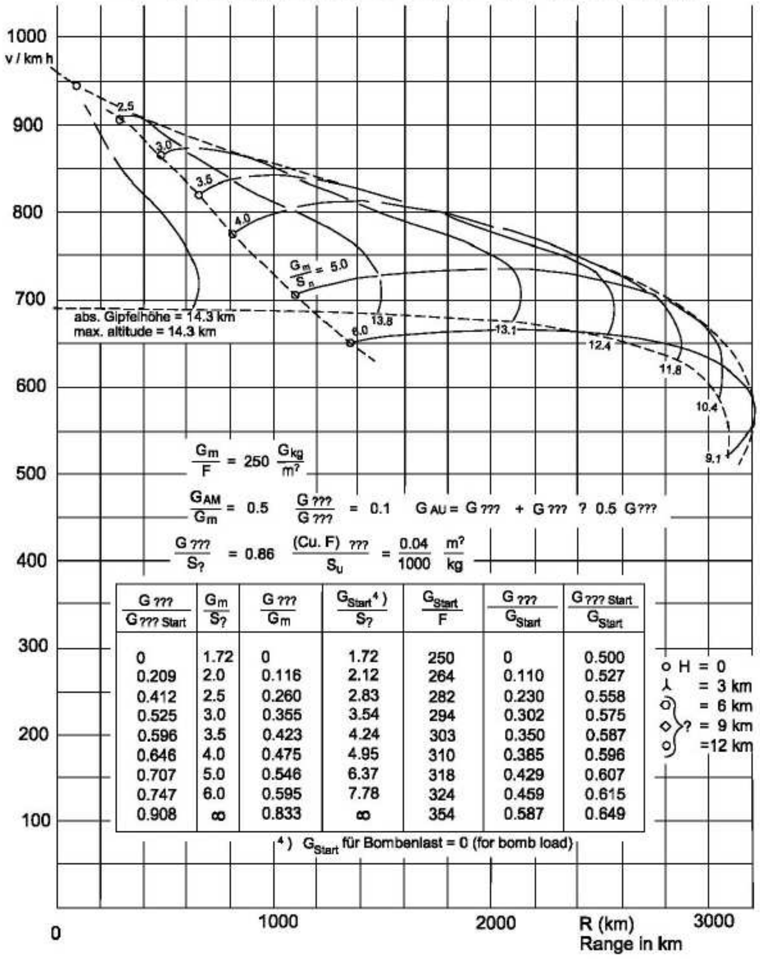
Note: Rudimentary reproduction due to partial illegibility of scanned copy.



$\frac{G_{???}}{G_{???\,Start}}$	$\frac{G_m}{S_?}$	$\frac{G_{???}}{G_m}$	$\frac{G_{Start}{}^{4)}}{S_?}$	$\frac{G_{Start}}{F}$	$\frac{G_{???}}{G_{Start}}$	$\frac{G_{???\,Start}}{G_{Start}}$
0	1.72	0	1.72	250	0	0.500
0.209	2.0	0.116	2.12	264	0.110	0.527
0.412	2.5	0.260	2.83	282	0.230	0.558
0.525	3.0	0.355	3.54	294	0.302	0.575
0.596	3.5	0.423	4.24	303	0.350	0.587
0.646	4.0	0.475	4.95	310	0.385	0.596
0.707	5.0	0.546	6.37	318	0.429	0.607
0.747	6.0	0.595	7.78	324	0.459	0.615
0.908	∞	0.833	∞	354	0.587	0.649

4) G_{Start} für Bombenlast = 0 (for bomb load)

Fig. 1
Ranges at full power, without start, climb, residual, etc.

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Figure 1 plots the air speed through range. For G_{Am} / G_m = 0,5 and with the coefficients of the JUMO 004 C, different aircraft, designated by G_m/S_o, have their full power performance delineated; the range increases with rising altitude and the air speed increases to some extent at first and then decreases somewhat. The upper graph line indicates the greatest achievable cruising speed, independent of the range, and at a random altitude. If a too-small aircraft is implemented, a somewhat slower cruising air speed is achievable than is indicated by the graph line but with a worthwhile top air speed.

Noteworthy is that the advantageous range for G_m/S_o is very small. The lighter aircraft achieve negligible increase in range while air speed is increased only minimally. Heavy aircraft, which are loaded with a large proportion of fuel, do not achieve a lengthening of the cruising range when air speed is strongly reduced. The reason for this is the decrease in altitude.

The graphic lines show altitude differences of 3000m for specific aircraft, which allows seeing the potential performances in those particular heights. Cruising ranges are very small near ground level.

The diagram was prepared to only show the characteristics of the power plants for a bomber, were other features, such as climb-rate, are not of importance. I have examined a number of other accounts, but I believe it would go beyond what we’re discussing here.

Schelp, Berlin (as guest): To augment what Herr Günter had said, I'd like to emphasize the fact that the first generation of power plants, which are now available today, are not meant in any way to be used for bombers, and I would appreciate it if these investigative efforts would be done with newer projects, such as the BMW TL 018 and BMW TL 012, which, due to their design details, are much more suited for such an application.

Günter: At first, I tried-out this illustrative presentation using the JUMO 004 C. The characterization of an aircraft by propulsion weight/operating weight through operating weight/take-off thrust, would be better to be replaced by weight of fuel/propulsion weight (the graph line was added subsequently). Nothing changes in the presented illustration, though. No deduction should be drawn concerning the outstanding importance of standing thrust; along with the increase of cruising range at higher altitudes, above all the potency of power plant out-put being reduced by the decreasing density of air is important. The diagram also shows that the increase of operating weight will increase cruising range only marginally. This limits the necessary idle thrust.

Schelp: What is missing here is the correlation with the airframe. More or less, one can vary the power plants' dependency on altitude, and this will continue to be an important part of this project; for what air speeds specific power plants are laid-out for. So in the future, it will no longer be possible to develop power plants without knowing beforehand the requirements of the airframe manufacturers. Only through the most intensive collaboration will it be possible to construct a solid package, comprising of power plant and airframe, which will result in getting as close as possible to the highest possible flight performances.

When applying these considerations, I used the maximum frontal area, because I believe that in the future the aerodynamic form of the power plant will approach a favorable value, so that this largest frontal area can be used as a characterizing aspect again. However, perhaps it is appropriate Page 31 to withdraw the questions until after Herr Zobel had brought forth his presentation. In examination of the climb rate of turbojet powered aircraft, it must be emphasized that when the power plant size is tailored to the airframe, this performance aspect will be higher than is possible with piston engined aircraft. One cannot look upon today's aircraft as benchmarks, since it is easily disregarded that they have once again got too heavy for the available power plants, which hampers their flight performance.

Multhopp: All calculations comparing performance of aircraft with different power plants have turned-out to be problematic. It is primarily due to the myriad of data that are required for assessing flight performances, which can be used to characterize those craft. It is only natural that one would sacrifice, for instance, for a superior horizontal air speed, a whole slew of other aspects of flight performances, such as having a high fuel consumption, inferior take-off quality, and etc. A closer look upon such things warps the overall picture substantially when one views in summary the presentation that Herr Schelp had brought forth. In addition, one must always keep an eye on all the concurrent details, which arise through the one or other type of power plant. It is, as an example, necessary when comparing weight differences between piston-engined power and turbojet power, to add the extra fuel that the turbojet uses during a climb to operating altitude onto the gross power plant weight. The turbojet reaches its greatest cruising range just below maximum altitude, but to attain this altitude, the engine uses about as much fuel as the weight of the power plant itself.

A rather one sided assessment of various power plants results when a random value, such as frontal area of the power plant, is taken as a basis. In aircraft construction, it is a given that a low drag is associated with a small frontal area. One tries everything that is imaginably possible to reduce the inherent drag to merely surface friction, and this is proportional to the surface area. Perhaps it would be more reasonable to use a 2/3 relation of the required volume as a comparing value, even though such a value still cannot give an objective enough viewpoint; it does not take into consideration the concurrent details that ensues for a specific type of power plant an aircraft manufacturer must deal with. The engine nacelle of a piston engines aircraft is often the only place where the landing gear could be placed, whereas the same can be placed only in the fuselage of a jet engined aircraft, since the wings on a fast airplane cannot be made thick enough. On the other hand, the cooling system of a piston engine causes enormous additional drag, which makes comparing calculation difficult because a lot depends on the method of placing this system onto the aircraft that, in most favorable of conditions, may change its overal design.

I do not want to give the impression of being against turbojet power plants, which we will soon be appreciating very much as a most valuable constituent in aircraft construction. I just wanted to emphasize that both types of power plants have their advantages and disadvantages, and thus must coexist side-by-side, and that research and development should not be steered onto a single path.

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Von der Nüll: A few of my colleagues have been working for about the past three months, on the comparatively same notion concerning diverse types of power plants. It turns out to be difficult to illustrate the attained findings, or rather to exemplify the comparing analysis in such a manner that satisfies the engine and airframe manufacturers. The number of variables that must be considered is so great, that they could possibly be viewed upon in a simplistic way. The differing performance requirement of aircraft lets the one or other variable become especially important. It would be desirable for the power plant manufacturer to hear from the aircraft manufacturer what independent variable they wish to have. Diverse possibilities of combinations are still available in the field of engine construction. It is difficult, however, to determine which of these would, in combination with aircraft type, represent a most favorable solution. This difficulty in communication also befalls the planning stage, because the required specifications placed on the power plant is made when the airframe is already developed. Naturally, the time for developing the desired power plant is not enough then. I would like to suggest that the aircraft manufacturers should put forth suggestions for purposive outlines for the comparative power plants.

Bock: The type of power plant has, in many cases, a profound influence on the landing gear. When assessing engine types, it is thus necessary to also consider the landing gear type. The given example shall exemplify this:

For sure, it is no coincidence that all aircraft these days that are powered by jet engines have nose wheels. The nose wheel weighs more than the usually used tail wheel, but it is more maneuverable than the latter. A disadvantage that all nose wheel equipped aircraft have is that the rollout of the plane after landing is relatively long in comparison, since the angle-of-attack of the wings is smaller than is the case with aircraft that are equipped with conventional landing gear. On aircraft that are propeller driven, the propeller is drawn upon to increase the air-drag considerably to help slow-down the plane. As far as I know, no such similar possibility exists with the jet engined aircraft, at least for now. It is therefore necessary to increase braking power on jet powered aircraft, which will bring certain penalties with it.

This little example illustrates that the valuable general statements from Herr Schelp can have only limited worth, and that each important individual case must be worked through exactly and be supplemented by similar studies.

E. Schmidt: In regard to the turboprop power plant, I would like to draw attention to the possibility of using multi-stage fan blades, which should bring certain advantages with this type of power plant. If the unit increases power out-put in relation to volume of air by increasing the allowable gas temperature to the turbine, the compressor stage draws a relative smaller portion of the turbine power, which proves to be purposive, at least at non-extreme air speeds, to avoid having the entire thrust energy be exhausted through the thrust nozzle, but to have a portion of it delivered to the propeller. By the … next lines illegible. … Page 33 to have done, such a propeller, even if it should be constructed as a multi-bladed, counter rotating unit, would possess a large diameter, which would have to rotate in a low speed. This would result in a tall landing gear, and also, due to the high gear ratio needed for the high rpms that the turbine produces, a large and heavy gear reduction unit. These disadvantages are eliminated by use of multi-stage fan blades that press air into a compression chamber, which then gets exhausted out of the thrust nozzle. By comparative power rating, the multi-staged fan-jet possesses a far smaller diameter and turns at far higher rpms than the propeller can, which allows its diameter to be smaller and the gear reduction unit simpler. Also, one could congest the air before the jet and so reduce the Mach number on the propeller blade tips. In addition, the pressure chamber behind the fan blades could offer a short term increase of power out-put by injecting fuel into the compressed air. These advantages are so substantial that one should take this type of power plant more into account when assessing jet engines.

End