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COMPONENT DESIGN AND DEVELOPMENT FOR FUTURE HELICOPTER ENGINES

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MTU MOTOREN- UND TURBINEN-UNION MÜNCHEN GMBH

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ABSTRACT

Development potential for future helicopter engines will be judged against the already high technology level of engines flying today. Further reduced fuel consumption will be of significance, but new development is only justified if it provides for improved overall system performance as well as reliability.

Design activity, to define the environment for component development, has to show good timing on two accounts. First, it needs to start well in advance to have proven technology available at the beginning of the actual engine program; second, timely reaction is required to changing customer needs.

Advances achieved today and results available from both rig and demonstrator test programs are discussed. These will form the basis for further component improvement, required to yield a successful next generation engine.

SYMBOLS

M_C	cooling air mass flow
M_F	fuel flow
M_{RED}	reduced mass flow
M_1	compressor mass flow
N	rotor speed
P	power
T_{Cl}	cooling air temperature
T_G	gas-temperature
T_{t3}	stator outlet temperature of the gasgenerator-turbine
T_W	wall temperature, local
η_C	compressor efficiency
η_{CE}	cooling effectiveness
η_{GGT}	gasgenerator-turbine effeciency
η_{IS}	isentropic efficiency
π	pressure ratio
π_C	compressor pressure ratio

1. TARGETS AND REQUIRED ACTIVITIES

The development potential for future helicopter engines will be judged against the already high technology level of engines flying today - powerplants that contribute towards this type aircrafts success as competitive and affordable means of transportation.

Yet, the very moment of their being successfully entered into service saw the industry busy giving birth to future engine proposals and initiating new component design and development.

This paper is a modest attempt at explaining the targets for development, the advances available today and future improvements in design methodology, required in order to render this exercise a significant step ahead.

For starters, Fig. 1 adresses the aspect of conserving fuel. It compares the levels of specific consumption over Take-Off-Power, that is the performance offered today with the targets for a next generation of engines. This improvement reflects more ambitious thermodynamic cycles matched to the aerodynamic and mechanical quality of advance technology components (Ref. 1). From that figure it also becomes apparent, that the range around 900 kW is not yet adequately represented. The effort required to advance component performance becomes evident when translating individual improvements into specific fuel consumption (Fig. 2).

However, reducing SFC cannot be the sole justification for new development. In spite of increasing fuel cost, it remains but one important aspect of engine economics, in which further reduced weight and volume, higher reliability together with better maintainability figure equally as high. Additionally, two vital aspects will be reflected by the engine design - the introduction of higher emergency ratings and the advantage of using a full authority digital control system. It is this requirement for better system performance and overall economics, resulting in reduced operating cost, that the industry is reacting to, when proposing a next generation of engines.

During the following discussion of component design and development, it appears prudent to bear in mind the physical size of engine parts involved (Fig. 3). This size effect becomes a primary, at times agonizing challenge to the designer, who tries to provide for both higher turbine inlet temperature and pressure ratio, while at the same time struggling to keep the gaining negative influence of secondary losses on component efficiency under control.

Considering the ever tightening schedules available for engine development, and in order to have proven technology and design methodology ready at the beginning of the actual engine program, it is paramount to:

- start early component development, with optimisation of performance potential in the rig and its substantiation under engine running conditions in a demonstrator
- timely react to changing customer needs, as well as the progress made within the ongoing development program and
- define a design, that will provide the proper environment to help realize the full potential of individual components in the engine.

2. ADVANCES ACHIEVED DURING INITIAL DEVELOPMENT

The work discussed here is oriented at the medium power helicopter, specifically the 900 kW engine class. A major portion of it being MTU's contribution towards a program called "MTM-Technology-Demonstration". It was jointly pursued with TURBOMECA and in part supported by the competent authorities in France and Germany* (Ref. 2).

Early design activity was initiated some four years ago to define the environment for component development. This resulted in the definition of a base line engine (Fig. 4), which at the time best answered the afore mentioned requirements.

In recognition of the small size of future powerplants, particular attention has been given to the selection of an optimum cycle (Ref. 3). The concept incorporated the highest potential for lowest specific consumption, optimized partload performance, short acceleration time and a life of 6000 mission hours. It consists of a variable geometry axial/radial compressor, a reverse flow combustor, a two stage gasgenerator-turbine and a two stage powerturbine with front drive. This set the environment for component work

- basic development in the rig, and
- substantiation of the technology level achieved under actual engine conditions in the Gasgenerator Demonstrator (Fig. 5).

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* in Germany the Federal Ministry of Defense (BMVg)

Out of the experience accumulated within that initial component work, but a few selected aspects will be touched upon (Ref. 4).

Gasgenerator-Turbine

Fundamental aerodynamic gasgenerator-turbine development was carried out with the aid of a cold rig (Fig. 6), designed to permit separate variation of the individual cooling air flows, i.e. to first stage stator, first stage blade and liner, and second stage stator. Aside from verifiying, that target efficiencies have been comfortably achieved, these tests have yielded very important answers, which will help to further improve the component (Fig. 7): Cooling airflow of the first stator effects capacity only, a factor when properly matching the gasgenerator. However, both first blade and second stator cooling air effect efficiency. Even though already moderate, this penalty can be further reduced by optimized cooling air reintroduction.

The ammount of cooling air required has a detrimental influence on cycle efficiency, as has been indicated before. Selection of high thermal strength material for the airfoils,together with good cooling effectiveness becomes of prime importance for structural design. Testing in the demonstrator (Fig. 8),using thermal paints, has made evident that cooling airflow can be reduced. For example on the first stage vane leading edge, temperatures of the hottest airfoil were within target, the trailing edge was cooler than design. Similar results were obtained for the other blades and vanes.

Combustor

The combustion chamber is a key component for a successful engine. In view of elevated turbine inlet temperatures, its own durability as well as its performance's influence on the life of downstream components are a, literally, vital aspect to insure high reliability and low maintainance cost. Adding the requirement for low emission completes the development task.

A reverse flow combustor has been selected for its superior potential of:

- low temperature distribution factors

- efficient combustion with low emission

- high stability and good relight

- excellent maintainability at reduced engine length.

However, these benefits, resulting from larger volume at hand for combustion and additional transition duct length available for dilution, have to be paid for by extra effort to control wall temperatures. It has to be realized, that this is not an easy undertaking, since both wall cooling and combustion require their adequate ammount of air. But today it can be reported that development progress made does safeguard a proper distribution, as verified by high pressure rig and demonstrator testing up to design speed and temperatures. Fig. 9 for example shows combustion chamber dome and outer transition duct after having run in the gasgenerator demonstrator. Turbine inlet temperature corresponded to Maximum Continuous rating, some 25 Centigrade below Take-Off. Wall temperatures are very uniform and nowhere exceed 1100 K. This was made possible by first optimisation of combustion in the primary zone and second the application of efficient wall cooling technology.

Compressor

As regards compressor development, MTU's own activities, outside of the technology program mentioned before and sponsored by BMFT*, will serve to underline advances and knowhow available today. They are oriented at providing fundamental knowledge on axial, as well as radial compressors (Ref. 5).

The reduction of axial stages to three, i.e. augmenting stage pressure ratio without sacrifice in performance, requires techniques to be applied, which, though at MTU proven for larger massflow compressors, have to be considered new technology for this size machine (Fig. 10)

- airfoils for high supersonic flow at the inlet

- supercritical, low loss, profiles to react to high subsonic flow in the middle cascades

- boundary layer control for the extremely loaded last vane

- casing treatment in the blade tip area in addition to variable geometry vanes for improved surgemargin.

To advance technology and establish design methodology, first detail analysis of individual stage performance was required. The results finally expected from rig testing the complete compressor are presented by Fig. 11: efficiency achieved throughout, pressure ratio and surgemargin are better than design.

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* German Federal Ministery of Research and Technology

Though still research oriented in nature, an axial/ radial compressor is, after having proven its potential in the rig, eventually scheduled to be demonstrator tested together with the turbine discussed before. Fig. 12 shows a preview - the rotor at check assembly.

3. DESIGN IMPROVEMENTS FOR FURTHER PROGRESS

While accumulating experience within the ongoing development program, the progress made and the development content have to be continuously monitored against the scenario of customer needs. Review and judgement are required, especially if priorities start drifting appart.

With the same emphasis on reduced operating cost, for a civil engine's Direct Operating Cost, lowest possible fuel consumption still outweights complexity, but for military application, where life Cycle Cost is concerned, reduced complexity and part cost may well become of prime significance.

A base line engine design per Fig. 13, reflects these considerations. It features a two stage axial/radial compressor driven by a single stage, highly transonic, gasgenerator-turbine. Initial and maintainance cost are greatly reduced. Because of extreme aerodynamic loading an efficiency penalty has to be accepted. This is however in part compensated - a simplified airsystem results in less leakage air and lower rotor relative temperatures permit reduced cooling airflow for the gasgenerator-turbine or an increase of stator outlet temperature. The latter effect having to be compromised for required life and improved cycle performance.

Component development has been initiated. Justifiably so, since, on the basis of the technological advances available today, it has been established that long range development potential will render superior system performance.

Compressor

In the compressor, more work is shifted into the radial stage (as is into axial stages). This will call for higher impeller tip speeds, resulting increased disk mechanical loading. Also, as a result of this change in work split, the efficiency of the radial stage will become a first order contributor to overall compressor performance.

Improved methods of controling shroud to impeller axial clearance need be devised to avoid significant losses (Fig. 14). For the same reason, coatings will be applied to the shroud, to ensure a smooth surface even after the occasional, but inevitable rub.

Combustor

It is considered, that the combustor has already lived up to its expectancies, no major changes in design will be required, though improvements are still possible. In order to further reduce temperatures, or , with the same temperature level, to allow for a more costeffective wall cooling scheme, the use of thermal barrier coating is under evalution. Test results (Fig. 15) indicate the potential to lower hot part temperatures significantly.

Gasgenerator-Turbine

The single stage, transonic turbine poses a three fold challenge to the designer:

- The effect of cooling air on turbine efficiency is of concern aerodynamically. As has been pointed out before, design methodology has been established.

- As throughout the engine, tip clearances remain the name of the game (Fig. 16), unfortunately they do not scale down with engine size, but for both steady state and transient operation their effect on performance becomes a dominating factor with the engine getting smaller and hotter. Active clearance control may be the magic word for large bypass ratio engines, where a relatively small ammount of fan air impinging on compressor and turbine cases works wonders for core engine performance - it does not trade for a small turboshaft engine. Here the only successful means will remain the careful thermal matching of liner to blade and disk. Analytical tools to accomplish this have been developed.

- To eliminate the axial excursions' influence on tip clearance, cylindrical liners are used in practically all modern engines. This approach is certainly a practical solution, but incures losses - tolerable for average loaded turbines, they are more detrimental for transonic stages with their inherently high levels of exit mach number. Sufficient flow area is required to hold this exit velocity within reason. These gasgenerator-turbine exit conditions also set the length of turbine interduct required to satisfy optimum power-turbine inlet conditions. Both velocity at entry and length will then be responsible for interduct pressure loss. Having chosen a cylindrical outer flow path, gasgenerator exit flow area can be had only by gradually decreasing the turbine hub diameter - this possibility being rather limited, before flow in this region and disk loadcarrying ability start to get in turn penalized.

Power Turbine

For future helicopter engines the power-turbine becomes a technological challenge in its own right. For a short discussion of design considerations Fig. 13 will be recalled.

Detail trade studies have been worked in terms of overall drive system - helicopter gearbox and engine - performance, resulting in the selection of a direct drive for the engine. To do this a twin stage power-turbine is necessary to accomplish the work. Rotational speed will be selected as high as possible, but limited by two considerations - the vibrational behaviour of the long through shaft and the compatibility with advance helicopter gearbox technology.

Still, to provide for best efficiency potential, power-turbine blade circumferential speed wants to be high. This renders the subject of PT-rotor structural integrity no longer secondary order compared to say the gas-generator-turbine. In terms of cost effectiveness, with no blade cooling required, an integrally cast wheel is feasible, but marginal with regards cyclic life and disk overspeed criteria. Here diffusion bonding (Fig. 17) presents an efficient technique to combine materials, casting for high thermal strength of blades and rim, powder metal for excellent low cycle fatigue life of the disk. As of today, structural rig tests have met all expectancies and this design is on the way to prove its potential in the demonstrator.

4. CONCLUSIONS

It remains then to conclude, that future helicopter engines will have significant improvements incorporated.

Technological advances and experience are available today as a result of early component development. Further progress is on route.

For final success of an advanced but simple engine however the decisive task lies with the designer, who will have to provide the suitable environment in this engine, to have its components operate reliably and efficiently.

5. REFERENCES

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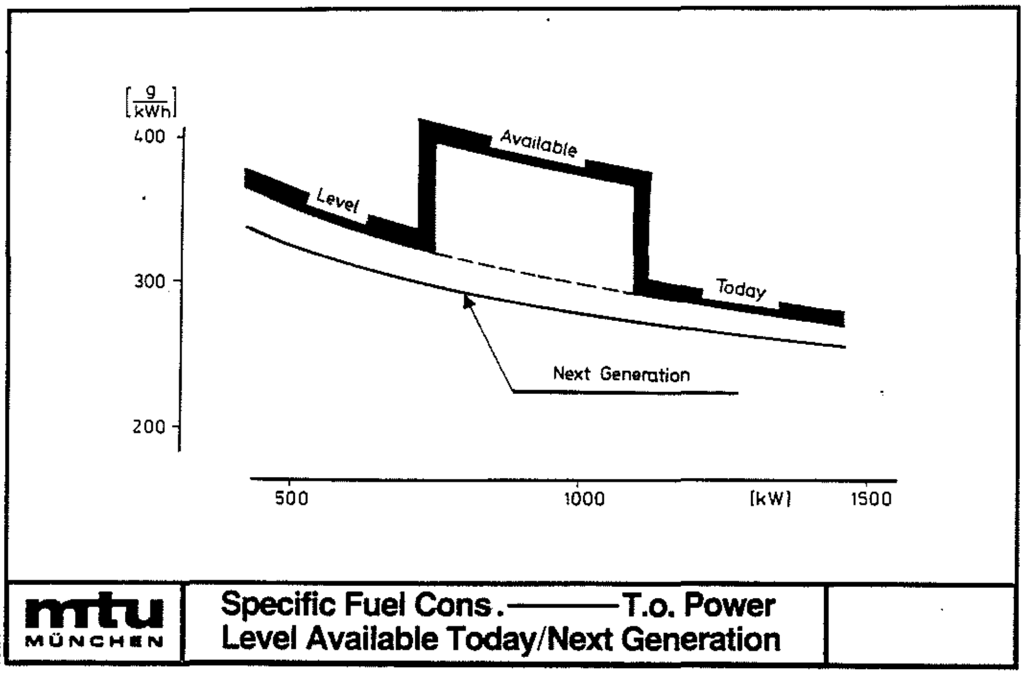


FIGURE 1

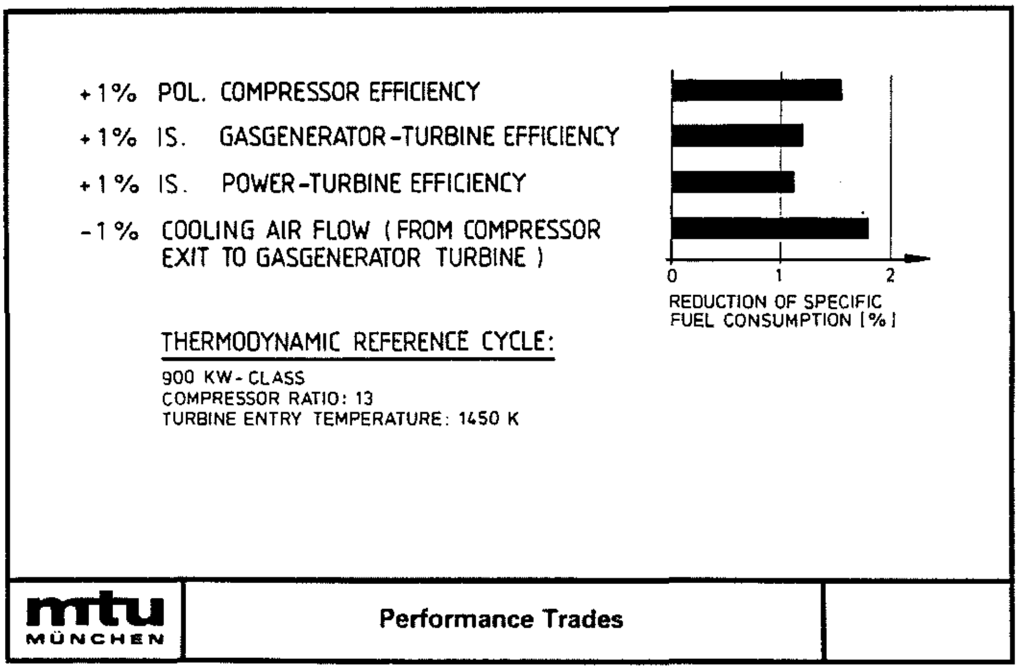
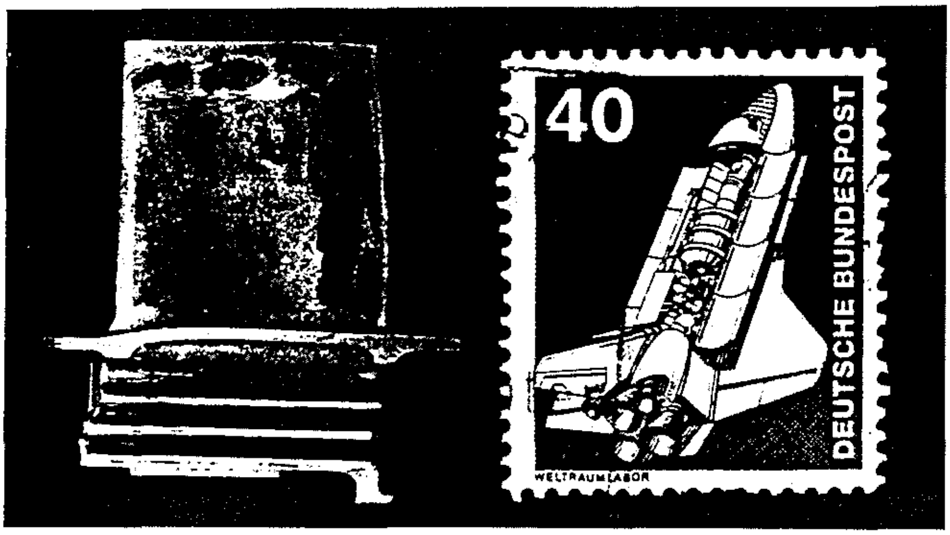
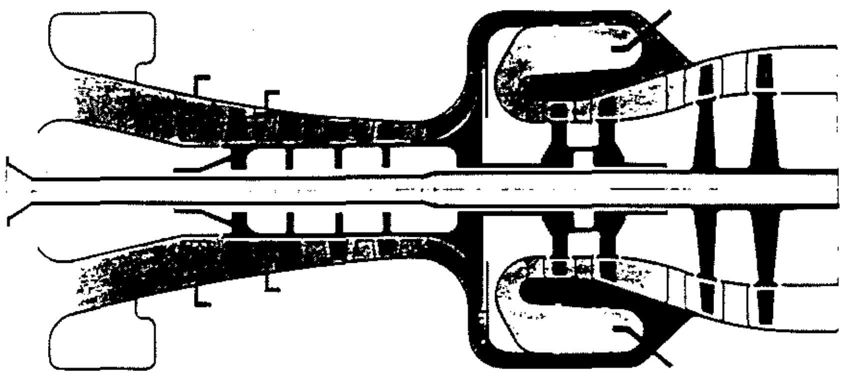


FIGURE 2



mtu MUNCHEN | Engine Size (900 kW-Class)

FIGURE 3



mtu MUNCHEN | **Base Line Engine** (900 kW-Class)

FIGURE 4

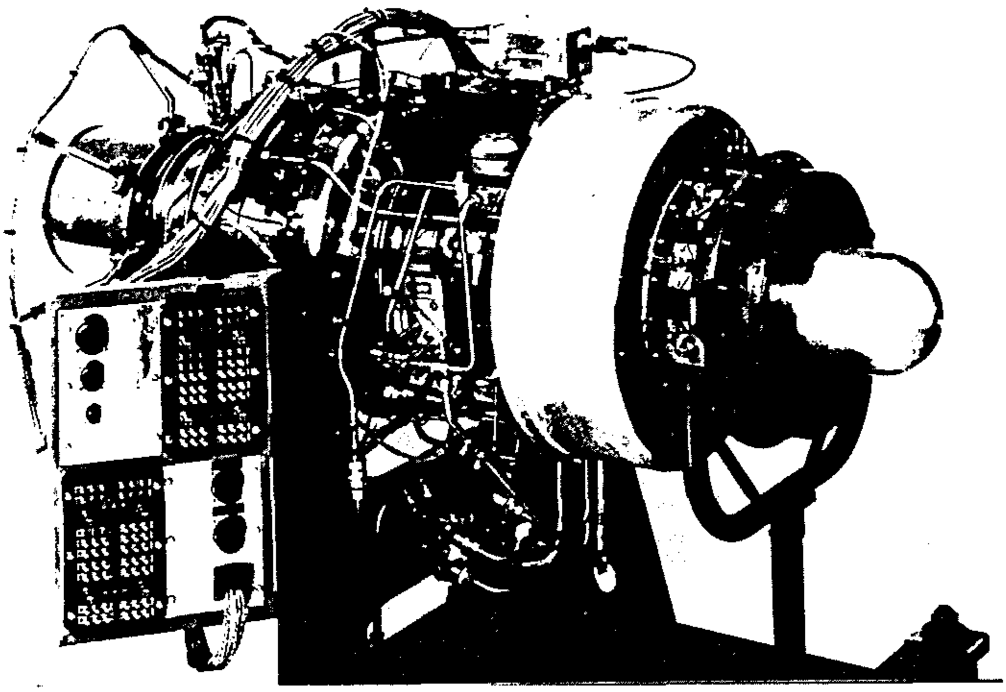


FIGURE 5

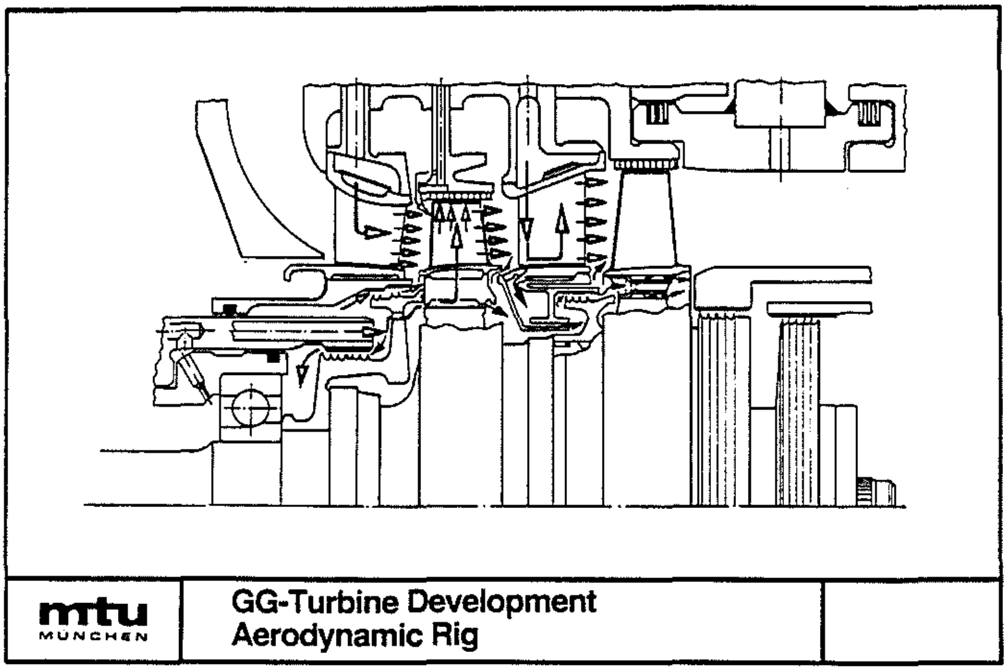


FIGURE 6

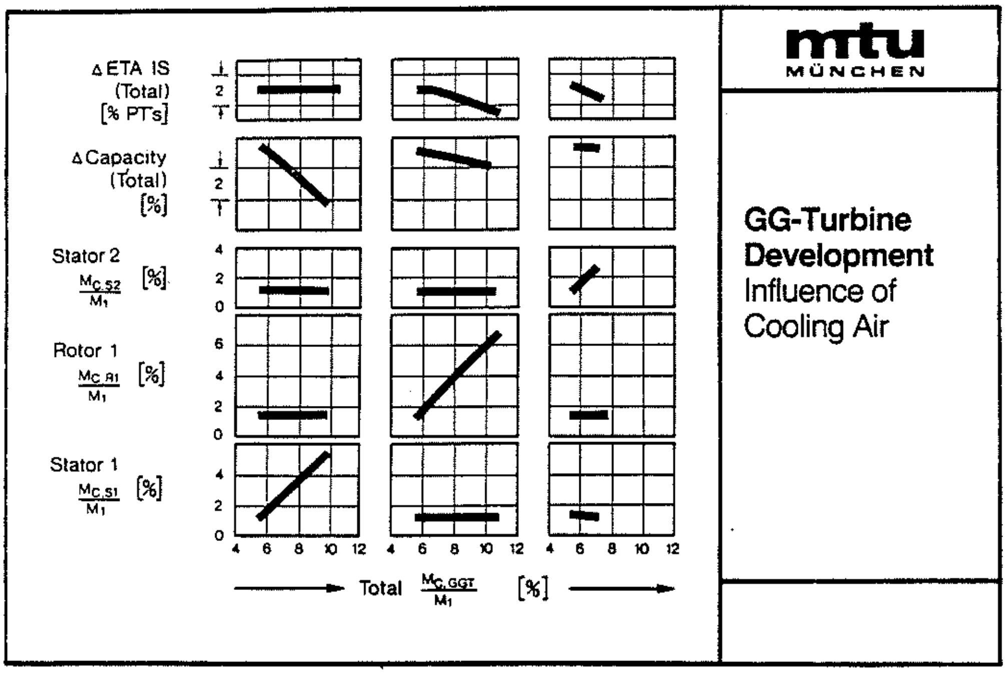


FIGURE 7

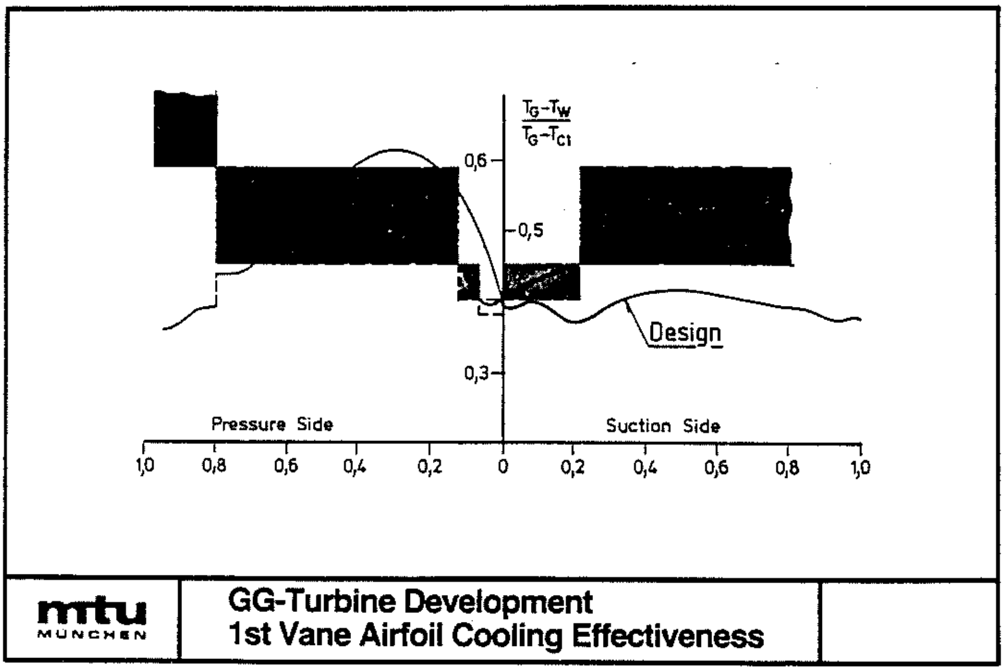


FIGURE 8

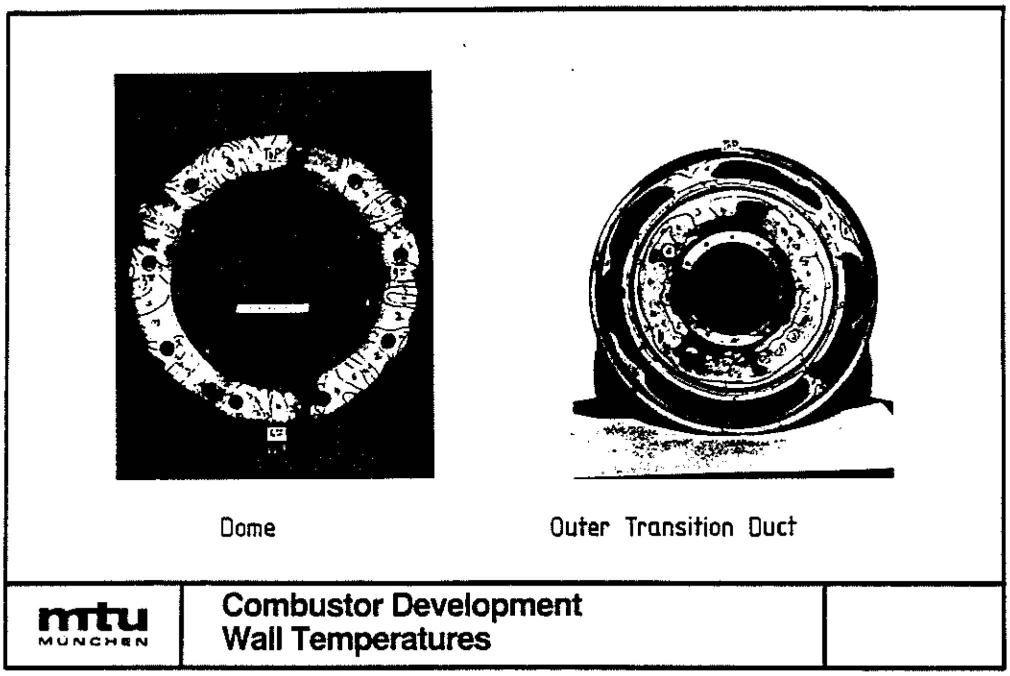


FIGURE 9

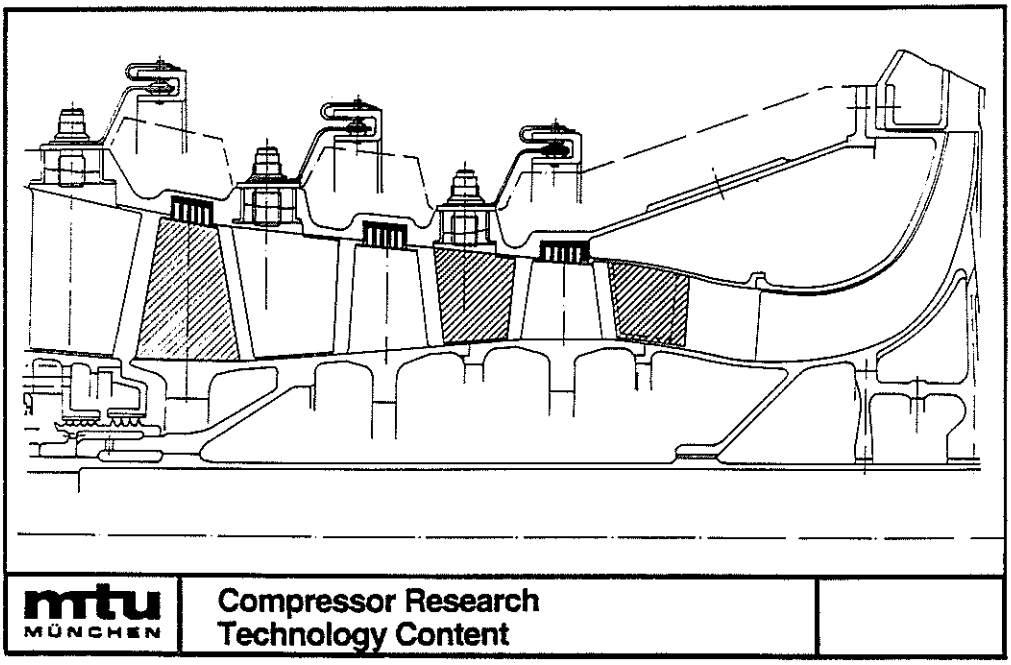


FIGURE 10

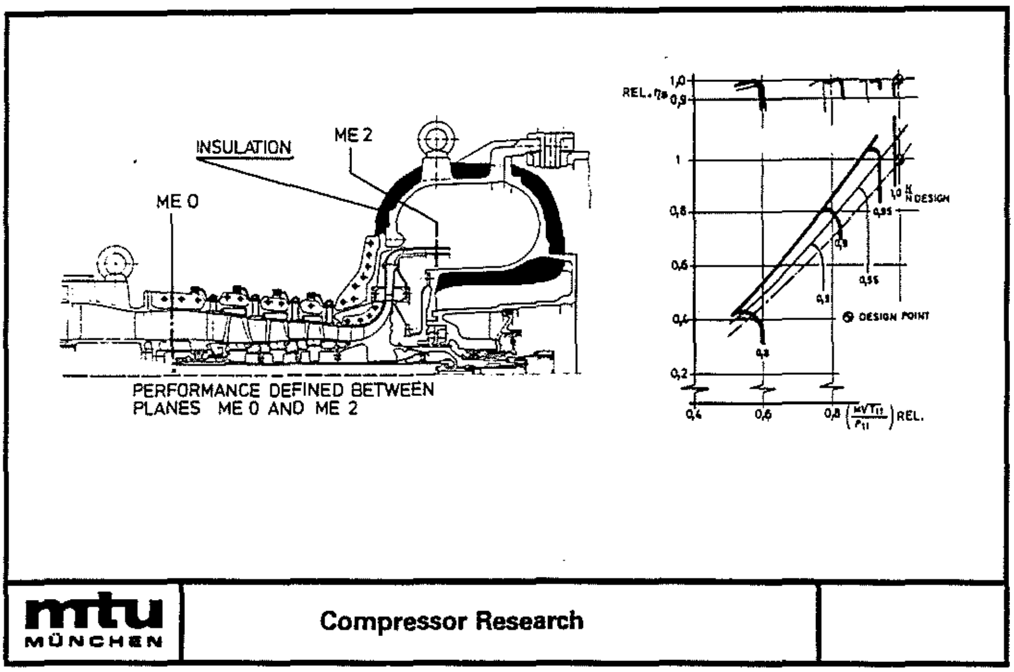
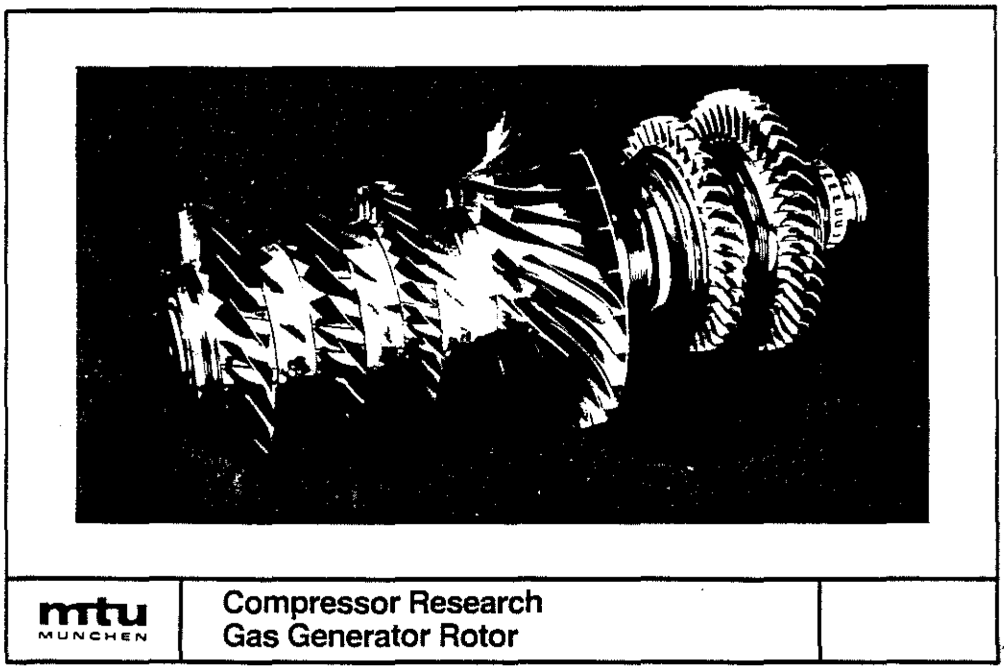


FIGURE 11



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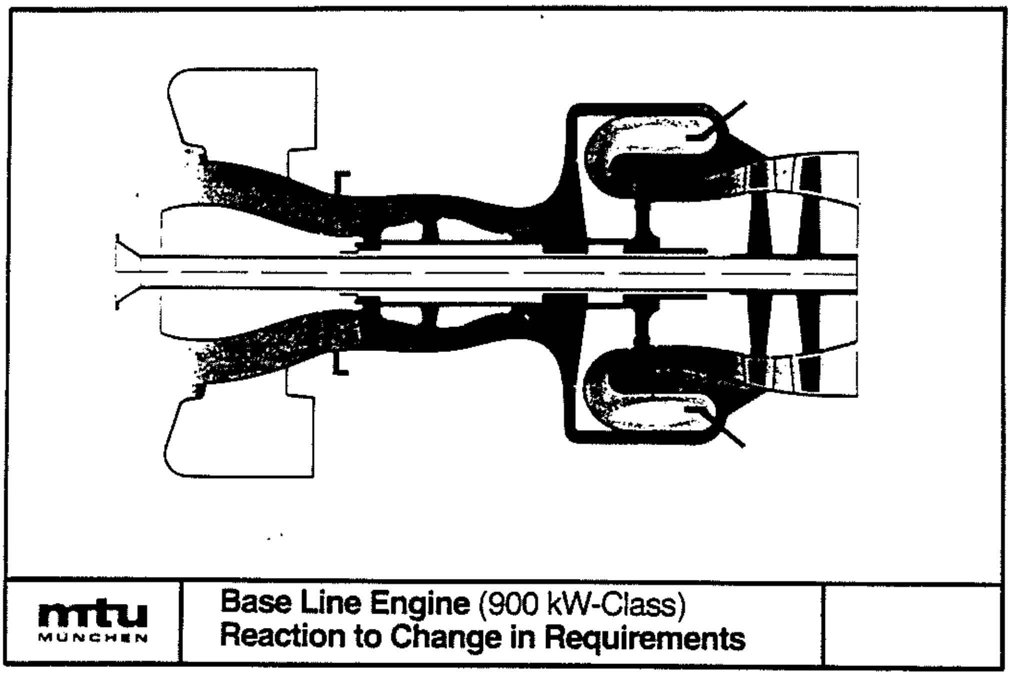


FIGURE 13

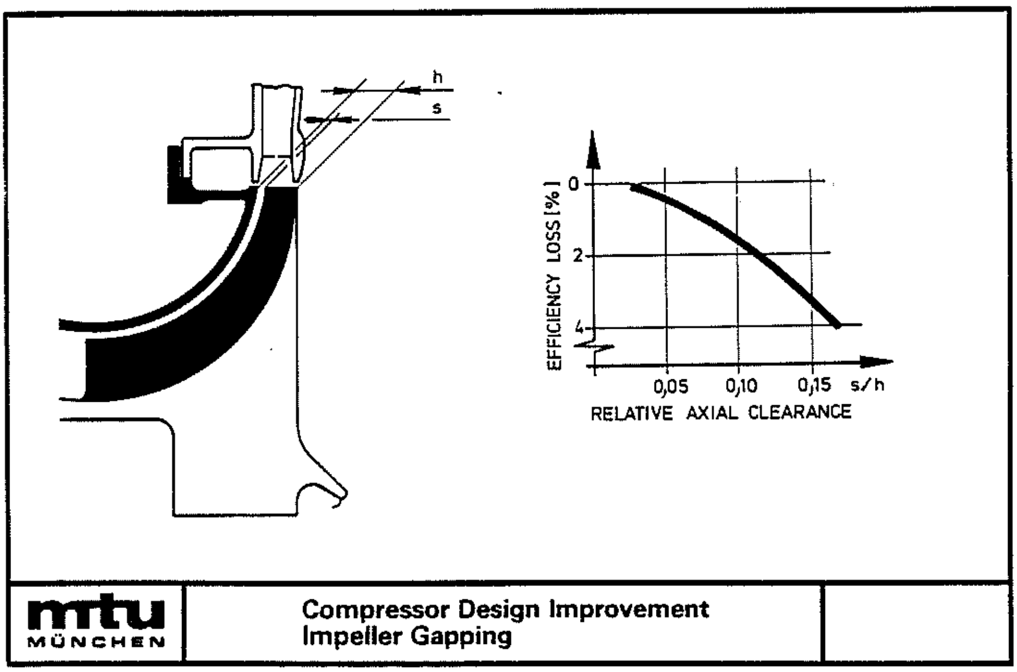


FIGURE 14

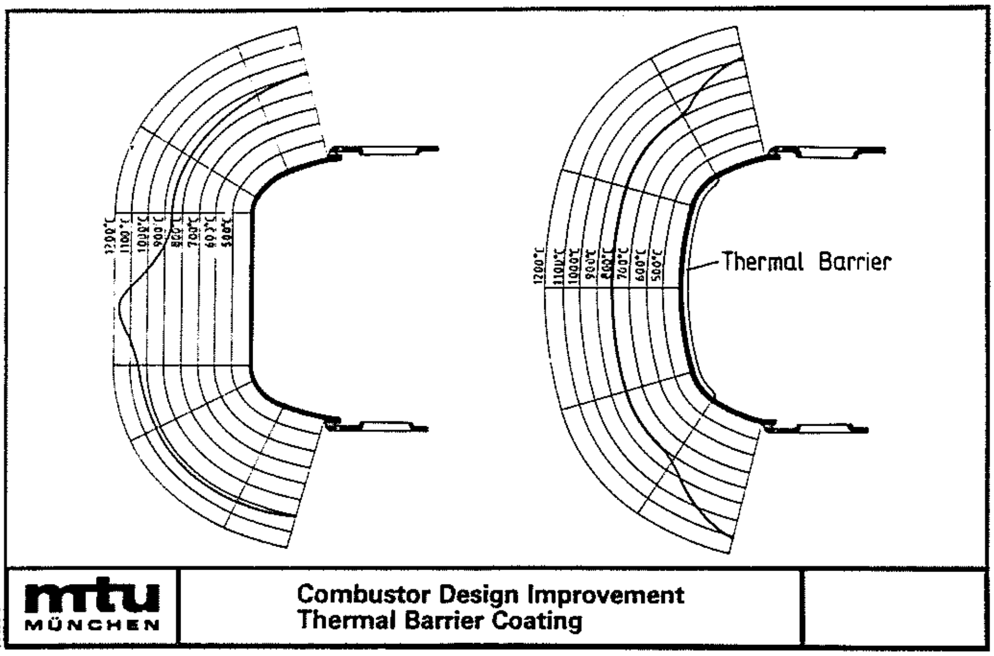


FIGURE 15

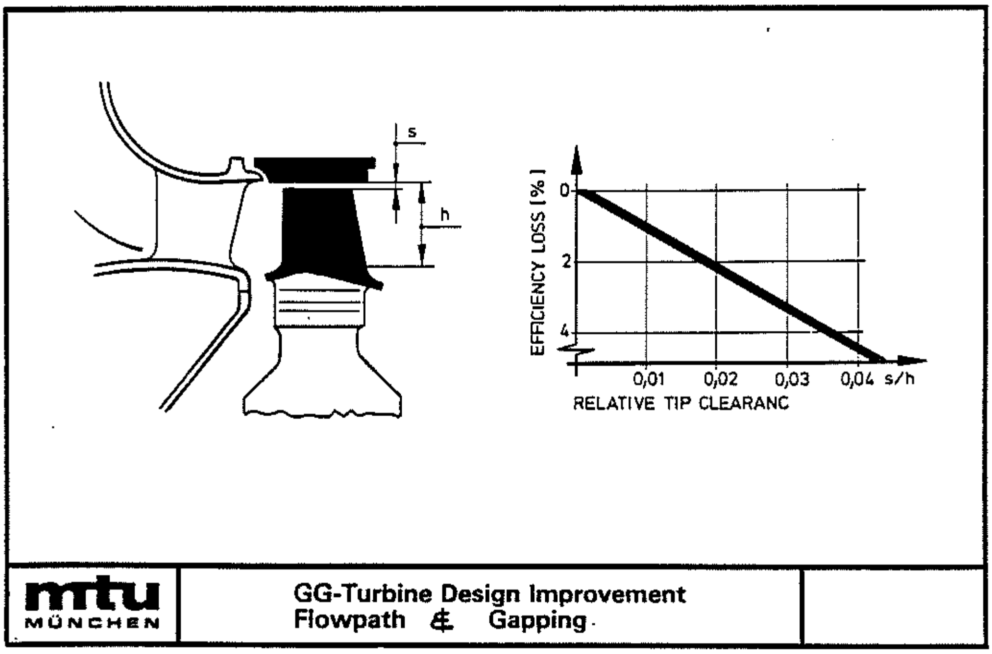
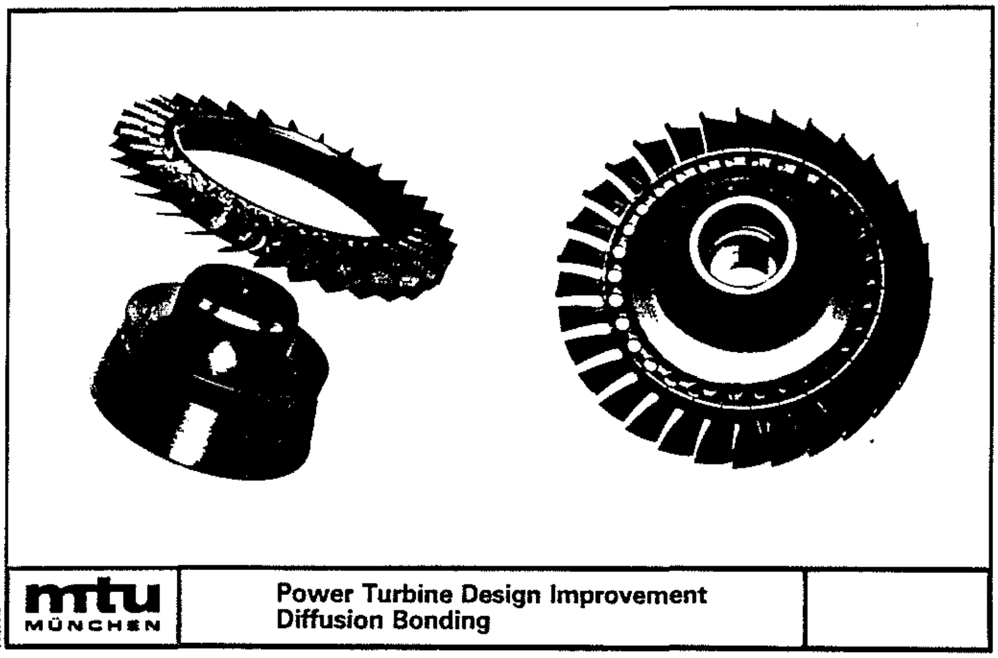


FIGURE 16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Power Turbine Design Improvement
Diffusion Bonding

FIGURE 17