AST3-CT-2004-502844

ADVACT

Development of Advanced Actuation concepts to provide a step change in technology used in future aero-engine control systems

Instrument: STREP

Thematic Priority: 4 (Aeronautics and Space)

Final Publishable Report

Period covered: Full programme - 1st July 2004 to 31st December 2008
Date of preparation: 14 June 2010

Start date of project: 1st July 2004 Duration: Four years

Project coordinator organisation: Rolls-Royce plc Revision: 01

1 PUBLISHABLE EXECUTIVE SUMMARY

1.1 Summary Description of project objectives

Control inputs to a gas turbine have remained largely unchanged since the products started to mature in the late 1950s, Recent developments in available actuation mechanisms have been identified as providing many opportunities for new control functions within a gas turbine which could provide a major step change in the capabilities of the machines. Internal company reviews and internationally reported programmes have identified many control functions and mechanisms that could be used. Variables on civil aircraft remain largely restricted to fuel input, guide vanes and bleed valves. All other components are designed as a compromise between efficiency at different operating conditions and the need to maintain stable operation over the entire operating range. There is a continual push to improve system performance for a number of commercial and legislative objectives. These can be largely grouped as cost, competitive position and environmental impact. Advanced Actuation will help to address these issues with improved engine performance.

The prime objective of the ADVACT STREP was to provide the technical background to enable the achievement of improvements in operation, availability, costs and environmental impact of gas turbines by the provision of extended in-flight actuation and control of engine parameters. This will include localised autonomous optimisation as well as interfaces with more conventional control systems.

1.2 Contractors involved

No.	Participant name
1	Rolls-Royce plc (Coordinator)
2	MTU Aero Engines GmbH
3	Snecma
4	Avio S.P.A.
5	Sheffield University
6	Turbomeca
7	Birmingham University
8	Dresden University of Technology
9	Institut National des Sciences Appliquées de Toulouse
10	Cambridge University
11	Centre National de la Recherche Scientifique
12	Industria
13	Office National d’Études et de Recherches Aérospatiales
14	Politecnico di Torino
15	Cranfield University
16	Von Karman Institute

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2 PROJECT EXECUTION

2.1 Overview

The prime objective of ADVACT has been to enable the achievement of improvements in operation, availability, costs and environmental impact of gas turbines by the provision of extended in-flight actuation and control of engine parameters. The work has investigated the applications and technologies to the stage where laboratory demonstrations have been completed and the requirements of the applications are understood. This has been particularly critical in the area of boundary layer manipulation for intakes and aerofoil cascade flows. Here, considerably more effort has been focused on understanding the flow phenomena under simulated conditions. This has emphasised the requirement to consider the application of actuation and not just the actuators. In this particular case, major strides have been made in the understanding of the flow phenomena, which have directed the actuator work.

Work prior to the programme identified the needs for work packages 2 to 6 where the basic technologies and application background have been developed and for work package 7 where the laboratory scale demonstrations have been constructed and evaluated. Work package 1 has assessed a broader range of applications, reaffirmed the choices of work package 7, provided more data for their assessment and identified potential for further research.

The justification for the introduction of further actuation within a gas turbine is an interesting issue. There are currently only three main actuation inputs for civil aircraft gas turbines, these are the fuel input rate, variable guide vanes and compressor bleed valves. This has largely remained unchanged since the 1950s although first generation tip clearance control has recently been added using thermal expansion of the casings. Around 20 opportunities for additional actuation have been identified, each one must “buy its way” onto the engine. Ie. it must provide positive benefits when all parameters have been taken into account. Currently available actuators have been assessed previously to address some of these opportunities, but limitations such as weight, temperature reliability and lifetime cost have precluded their adoption. The novel applications and technologies which have been investigated within ADVACT hope to address some of these limitations.

Application studies identified the expected performance benefits from a number of applications. Selected applications were also evaluated further to consider the application requirements such as installation, failure modes, risks etc. One particular area which deserves further mention is the operating regime. The emphasis of gas turbine performance development has traditionally been around increasing cruise efficiency. The engine must however still operate over a wide range of conditions and on short haul operation, can dominate the fuel burn requirements. The requirement to operate over a wide range of conditions leads to severe compromises which might be overcome by additional actuation. Figure 1a shows this traditional approach where the peak efficiency is at cruise. Figure 1b shows the effect of increasing the efficiency to this level at all conditions, the overall benefit is quite small. Figure 1c shows the expected effect of an adaptive improvement at cruise. This may be extended to multiple points as shown in Figure 1d. This approach does require the adaptive system to give a very efficient operating point. An alternative approach is to use an adaptive system at a point which causes compromise to be made at other conditions as shown in Figure 1e. This can potentially allow dramatic changes over the whole of the remaining conditions. This may, for example, involve actuation at start up or take off to remove the compromises at all other conditions. It also has the advantage the the actuation system might not need to be highly efficient, because it is only used for a short period.

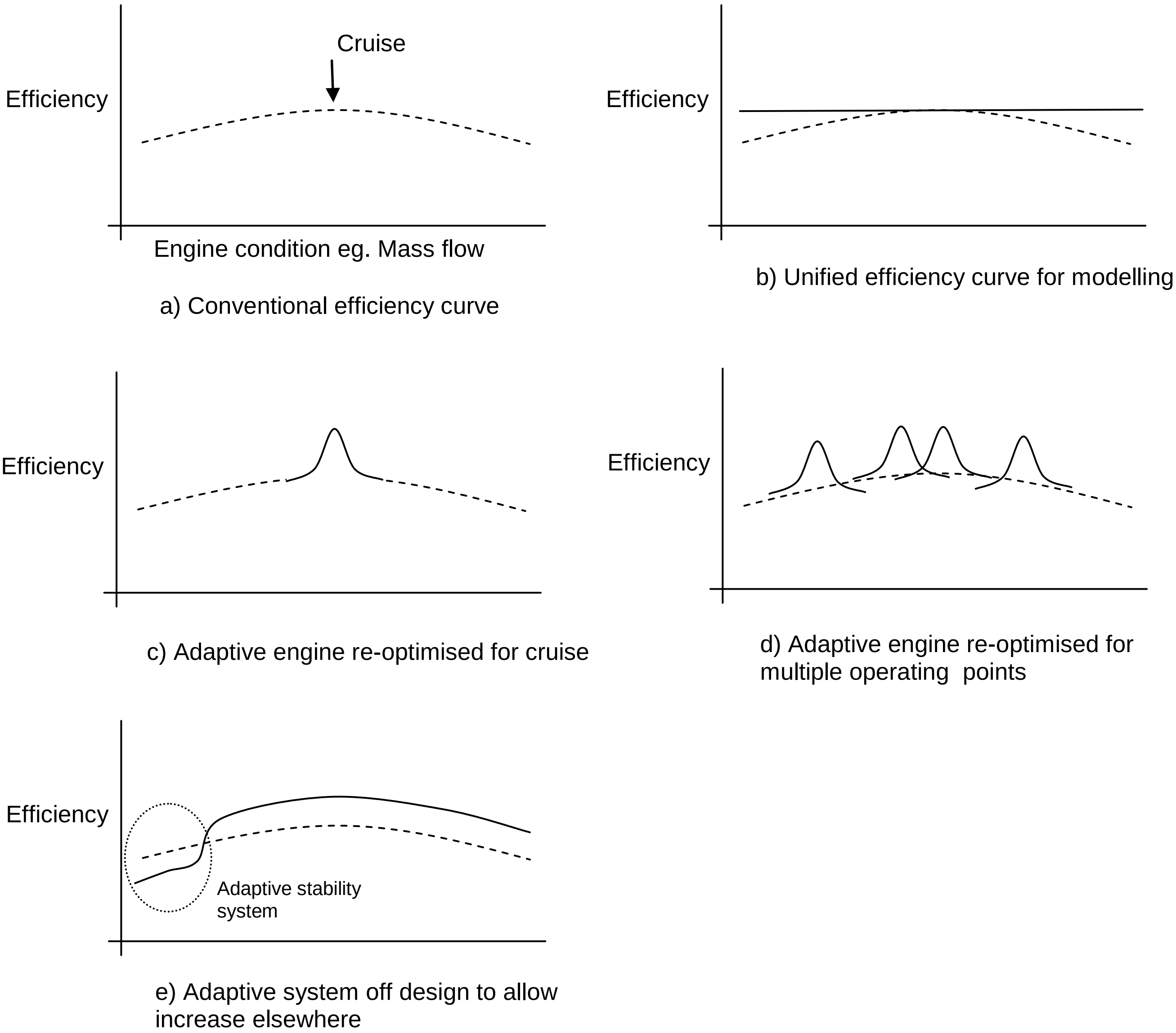

Figure 1 Operating regimes for adaptive systems

2.2 Technologies and applications

The key technology areas which have been actively pursued within ADVACT are

MEMS devices for microvalve fabrication

Boundary layer manipulation

High temperature Shape Memory Alloys (SMAs)

Large section Shape Memory Alloys (SMAs)

High temperature Electro-magnetic (EM) actuators

Rotordynamics and vibration control systems

These have been demonstrated for the following applications within work package 7.

Flow control for drag reduction and turning in aerofoil cascades

Flow control in engine inlets

Variable geometry final nozzle

Variable geometry aerofoils

Blade tip seal position control

Shaft bearing with Active Magnetic Damper (AMD)

A high temperature fuel staging system was also designed, but could not be produced within the time scales of the programme.

Other actuator technologies and applications have been considered and are discussed in the reports from work package 1. Several opportunities have been identified in these additional studies which could be considered for future programmes.

2.3 Boundary layer control and MEMS devices

2.3.1 Background

The state of a boundary layer can have a significant influence on the ability for an air flow to remain attached to the surface. Control of the boundary layer can maintain attachment for longer, cause detachment or increase the amount of turning achieved by an aerodynamic device. Continuous sucking or blowing of air through the surface to affect the layer has been known for many years. Modulated or high frequency pulsed blowing to achieve a similar effect has been under investigation for airframes for around 15 years. Claims of improved control, significantly reduced energy input or loss have been made.

Two potential applications for gas turbines have been investigated within ADVACT. These are for flow control in intakes and on aerofoil cascades. Intakes would benefit from improved control during the infrequent events of high incidence operation such as cross winds, rotation and spillage during windmill. This would allow a thinner intake lip to be used which should lead to greater efficiency at all other times as shown in Figure 1e. Aerofoil control should give improved efficiency or operating envelope and may provide an alternative for mechanically actuated Variable Guide Vanes (VGVs).

As discussed in deliverable 1.3, use of these devices for take off may result in an efficiency penalty whilst deployed, but allow major benefits at all other conditions. A specification was prepared for IEMN to produce the MEMS based valves which have then been evaluated at ONERA, Cambridge University and VKI under differing conditions.

A major proportion of this activity has been to understand the aerodynamics of the applications in order to produce a specification for the actuators. This demonstrates the major interaction between the actuator and the application and the need to develop the two in parallel. It is not simply a matter of adapting an existing actuator. This emphasises the need for the word “Actuation” in the ADVACT title instead of “Actuators”.

2.3.2 Progress

The preliminary specification for a pulsed jet was developed in the early part of ADVACT. It identified a significant difference between engine and airframe requirements. The higher velocities and more aggressive conditions within the engine require a high momentum transfer which is unlikely to be achievable by synthetic jets which have been identified as attractive for airframe aplications. There were also serious concerns over device blockage by this approach.

The ONERA work has concentrated on the fundamental flow understanding and the effect of vortex generators and jets in gas turbine flows. Significant improvements in separation were achieved with both fixed vortex generators and modulated jets.

The ONERA and MTU models showed that from an industrial point of view, combinations of several methods to model the small and large scale elements within the flow and to use local mesh refinement methods gave a good compromise between accuracy and computational effort. Typical results are shown in Figure 2. These methods suggested that modulated blowing should be effective and that a very short (< 10%) duty cycle should be advantageous within a blade cascade. This has significant implications for the power requirement to drive the jets. Typical characteristics of these jets were identified as less than 1mm diameter, with modulation frequencies of greater than 10kHz.

Initial work on an actuated jet modulation device at IEMN produced an array of jets (Figure 3) which were evaluated in the ONERA wind tunnel. These made a significant contribution to the understanding of the fundamental flows, but with a maximum frequency of 180Hz were unsuitable for further work at VKI or Cambridge.

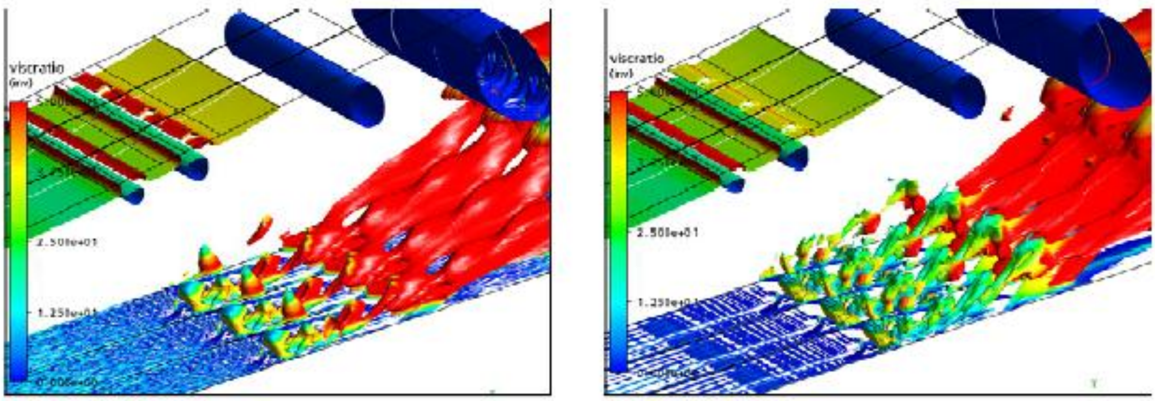

Figure 2 RANS (left) and DES (right) simulation of the flat plate experiment

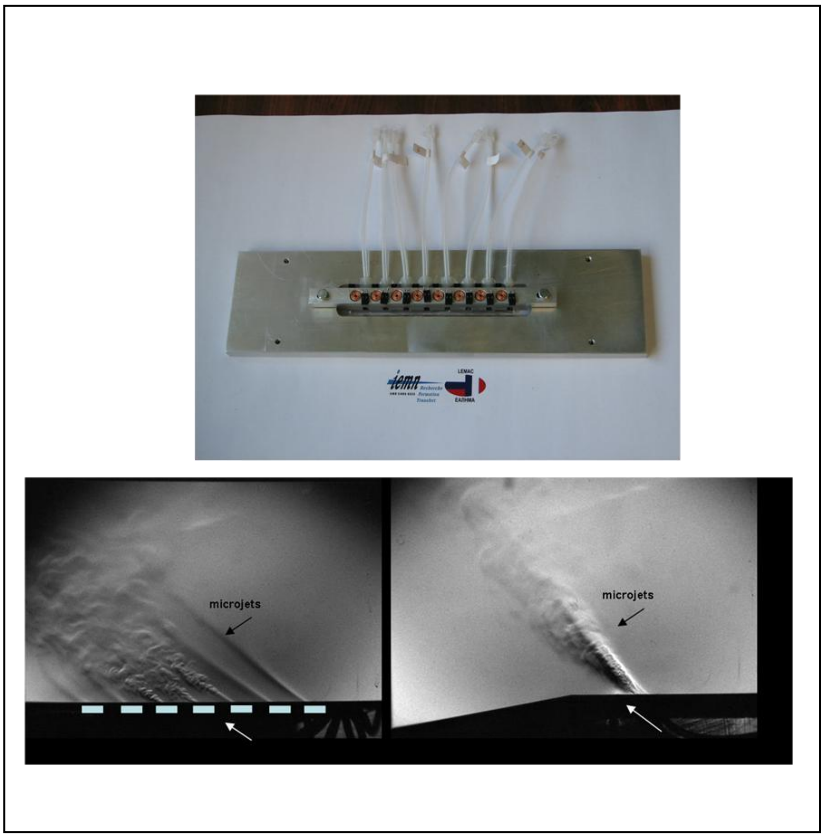

Figure 3 Array of mounted microvalve and shadowgraphs of working valves

The aero modelling work suggested that full frequency control was unnecessary and that higher frequencies were desirable. A fixed frequency, passive modulator was suggested by the industrial partners and pursued by IEMN. The general configuration is shown in Figure 4. This achieved a modulation frequency of 2.2kHz and a peak velocity of 90m/s. Significantly, the valve produced very little flow between pulses, with the velocity dropping to almost zero.

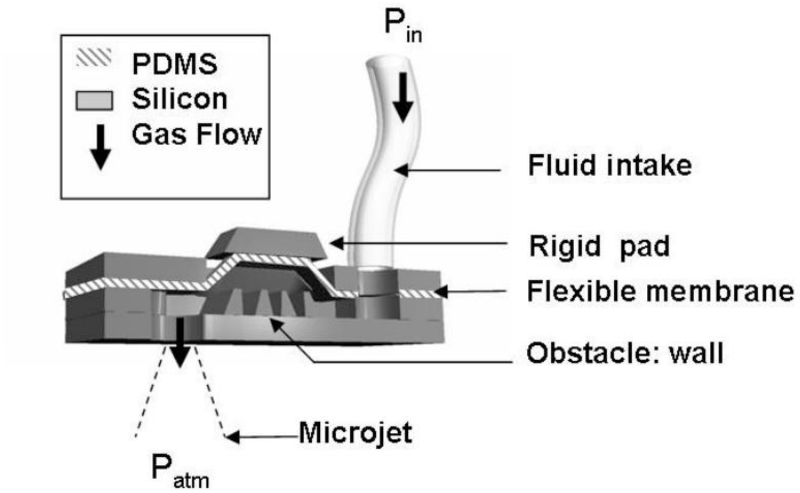

Figure 4 Self oscillating microvalve concept

The aerofoil cascade work at Cambridge developed significant new understanding of the technology and the difficulties involved with implementing it, even on a rig.

Tests on a cascade rig showed a drag reductions in the order of 50% relative to a blade with out control. Under the measured conditions, the use of modulated blowing reduced the mass flow requirements by 40% compared to continuous blowing.

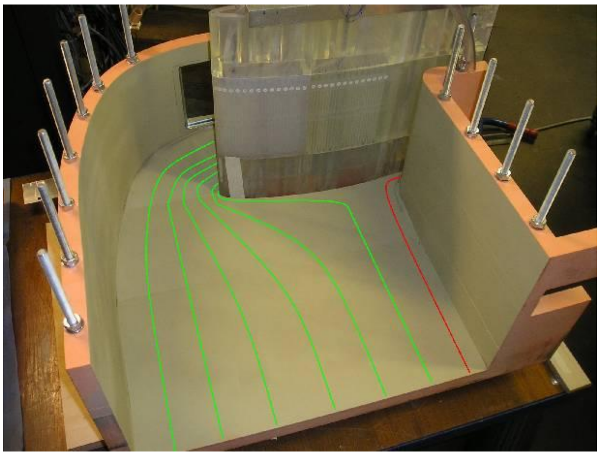

Figure 5 Intake sector rig

Major progress was achieved in simulating and controlling boundary layers within an intake. Experimental techniques are well advanced and a macroscopic simulation of the modulating microvalves was successfully deployed. The microvalves unfortunately arrived too late in the programme to be evaluated within the rig.

2.3.3 The way forward

Flow control within the ADVACT programme was a very ambitious activity within the limited budget available. The prime objective of ADVACT of providing a preliminary investigation which would indicate the potential for the technology and the way forward has been achieved.

Within the limitations of the work, continuous blowing of microjets has been shown to be effective in achieving flow control in both applications. Modulated blowing has been shown to give improved benefits, but the issues and full advantage were beyond the scope of the current programme and identified the opportunity for further developments.

The production of pulsed microjets has proved to be problematical. The work has shown the potential for manufacturing by MEMS technology, but has also highlighted many difficulties. The potential to use a fixed frequency device is a significant step forward and will greatly simplify future activities.

Follow on work to investigate intake flow is progressing at Cambridge University, where the potential for noise reduction using this technology is also being pursued. The work has also fed into compressor stall activities in the NEWAC framework 6 programme.

2.4 Shape Memory Alloys

2.4.1 Background

For most practical actuator applications, the SMA is loaded by an external spring element. When heated, the SMA will move towards a pre-set shape, when cold, the SMA can be deformed to a different shape by the external spring. In this way a repeated two way actuator can be produced. SMA is frequently assessed as having one of the highest energy densities of all actuators. It has been reported by NASA that SMAs have over 5000 times the specific energy (energy per unit weight) output of an electrical solenoid. The materials are essentially “solid state” and can be formed into actuators with no conventional moving parts ie. they have no sliding interfaces. They have the potential to be fully integrated into a structure and have been shown in ADVACT as suitable for use as a structural part of the component. They can supply strains of up to 8%, although 2% is a more practical limit for repeated actuation, with stresses in excess of 200MPa readily achievable. Due to the heat actuation, the response is slow in anything other than very small scale applications, but is ideally suited to high load adaptable components where ambient temperature can be used as the actuation input or infrequent use is required.

Partially due to domination by the medical market, but also due to metallurgical limitations and the need to maintain very accurate composition control, production had previously been limited to small sections up to around 10mm wide strip or 2mm diameter wire. Commercial alloys are also limited to a lower transformation temperature (M_f) of less than 30^0C and a maximum environment temperature of less than 200^0C. The 99.5 percentile high temperature at ground level for all airports is 45^0C. This dictates that an M_f temperature in excess of 50^0C is essential for virtually all civil gas turbine applications, where the ability to retract the actuator is required in all environments.

Although intrinsically very attractive as a gas turbine actuator, the need for higher temperature operation, larger sections, improved modelling and more convenient application were identified. Activities within ADVACT have addressed these requirements as below

2.4.2 Progress

Development of large sections of improved temperature (M_f > 50^0C) alloys. A titanium rich alloy has been identified as the most appropriate to achieve the specification. Large sections 350 x 250 x 4mm of consistent material can now be achieved and can be subsequently processed and machined into components. This gives an M_f temperature of 55^0C, although some reduction of this occurs on subsequent thermal and mechanical cycling. This size of sheet is sufficient for the application to the adaptive nozzle investigated as another part of the programme.

Development of large area actuator coating methods has been achieved, with very robust coatings formed. A titanium compressor blade was coated by low pressure plasma spraying with NiTi SMA by as shown in Figure 6, although further work will be needed to operate this as an actuator.

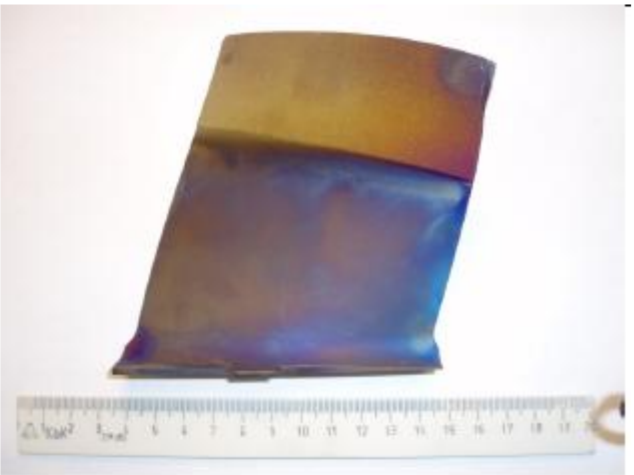

Figure 6 Titanium compressor blade coated with NiTi SMA

Characterisation methods - although many papers have been presented on the characterisation and modelling of SMA, they seem to be in two categories of over simplified or over complex. Both are currently impractical for detailed mechanical design of the structures investigated in ADVACT. New methods have been developed within the programme which allow straight forward measurements to be used and enabled major advances in practical engineering design methods.

Actuator design methods. These have also considered the design of the structure and it's actuation. The original concept of a structural element pre-stressed in bending balanced by an SMA element in tension (Figure 7) has proved to be very successful. Simple test pieces have shown very good agreement to validate the methods.

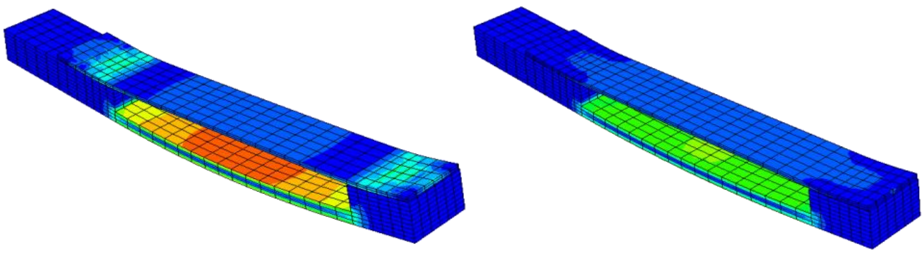

Figure 7 Compound element approach to SMA bending structure

The "wavy" variable area nozzle concept for controlled variable area of a civil engine nozzle has been successfully modelled by finite element methods and a working demonstration produced (Figure 8).

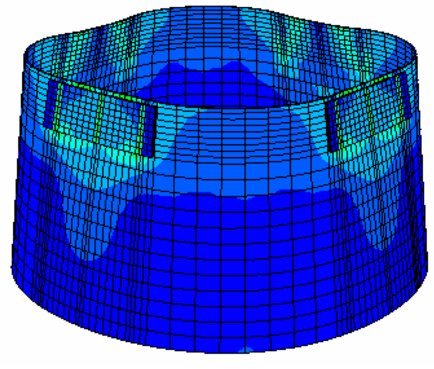


Figure 8 Finite element and demonstration model of wavy nozzle

Very good agreement between this new engineering modelling method and the test pieces have been obtained. Similar success has been achieved with agreement between the morphing aerofoil modelling and design.

2.4.3 The way forward

Work is continuing under other programmes to further investigate and develop the potential for these structures. Work in parallel with ADVACT has produced a single sector of an experimental variable area nozzle which uses a lower risk interlocking slats approach (Figure 9). This has been successfully evaluated in a wind tunnel where full simulated flight cycles were achieved.

Figure 9 Post ADVACT wind tunnel model of interlocking slats variable area nozzle

Higher temperature alloys have already been considered in the EU framework 7 proposal SAMANTA, this received a very favourable review with the EU, but support was dropped by the Engine Industries Management Group (EIMG) in order to promote more main stream materials programmes. With the completion of the ADVACT programme, the need for this work is now much clearer and has improved confidence of success. Re-submission should be considered to start development to realise the potential for enhancement of the core gas turbine engine by SMAs.

The availability of large section, repeatable SMA material is a major step forward in expansion of the opportunities in larger scale, robust applications. SMAs are expected to have significant cost and lifetime advantages over more conventional systems such as hydraulics or electrical, but will clearly need significantly more development.

2.5 High temperature Electro-magnetic (EM) actuators

2.5.1 Background

Conventional electromagnetic (EM) actuators are highly versatile, but are typically restricted to around 200^0C, primarily by the insulation. This is a severe limitation for gas turbine applications, where the area just outside of the core engine is typically up to 360^0C. All types of EM actuators including solenoids, motors etc. are of course used in cooler areas for applications ranging to small valves to thrust reverser actuation. Numerous potential applications have been identified ranging from turbine tip clearance to fluid system controls. The former would greatly benefit from a practical actuator which could operate at up to 700^0C.

2.5.2 Progress

The work has progressed in the two complimentary areas of coil and system design. Early reviews identified the available technology and applications. Although actuators capable of operating at up to 800^0C had been developed at Sheffield University prior to ADVACT, there is still a need for a major step change in technology before these could be viable for gas turbine applications. The reviews identified a good match between potential applications and technology suitable for demonstration within the ADVACT timescales to give capability to operate in ambient conditions of up to 360^0C. Effort has been concentrated on direct linear EM devices.

The results reported from work package 5 developed a technology to provide coils with a practical environment temperature limit of 400^0C, a major improvement over previous capabilities. It is a fundamental enabling technology and will have a significant impact on many applications outside of the two investigated here. Design of coil heat transfer has also seen significant advances.

Simple attractive coil systems provide a high holding force, but the force reduces as the inverse square of distance. Even with a requirement of only 1.5mm in the compressor tip clearance application, this greatly increases the size and hence weight requirement. A novel grooved armature and stator design has been developed which greatly extends the useful range of force actuation (as shown in Figure 10).

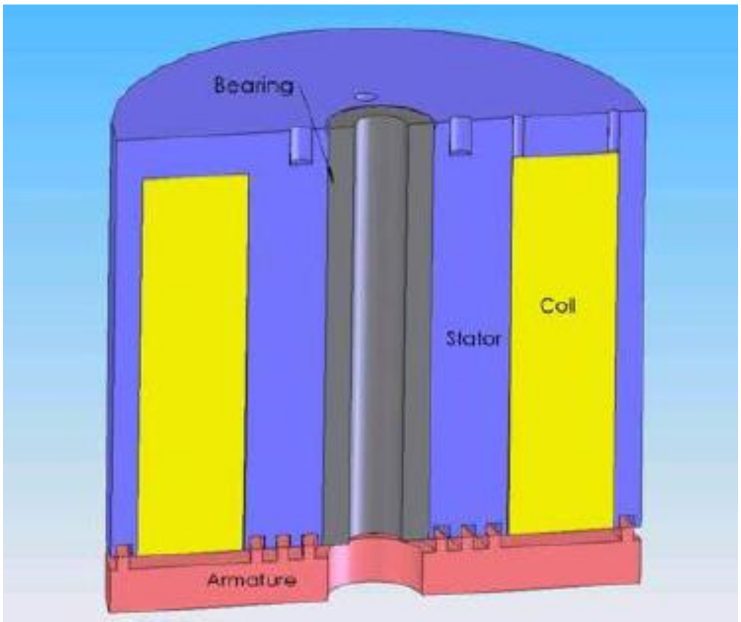

Figure 10 Section of EM actuator for tip clearance application

A practical device was built and demonstrated for compressor tip clearance control at elevated temperatures as in Figure 11. Although currently too heavy for aircraft applications, the approach has been further developed in NEWAC and considered for turbine tip clearance control in the Environmentally Friendly Engine (EFE) UK programme.

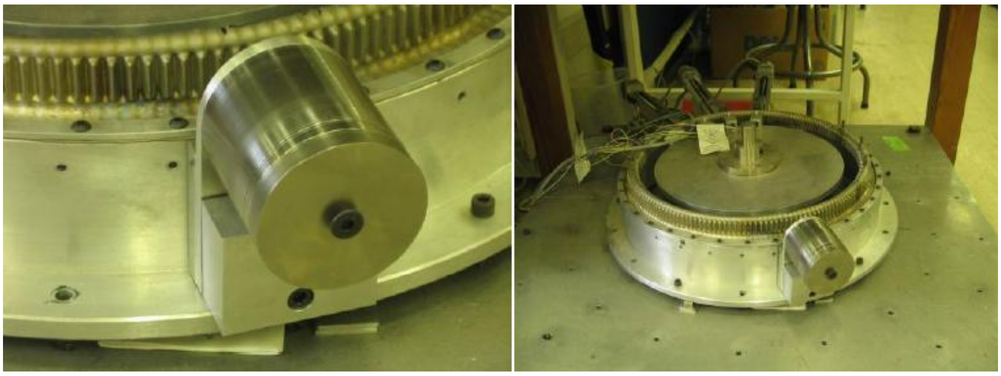

Figure 11 High temperature actuator applied to experimental tip clearance ring

Although it was not possible to produce a high temperature fuel valve within the programme, a thorough application and component design study was completed. The valve element is shown in Figure 12.

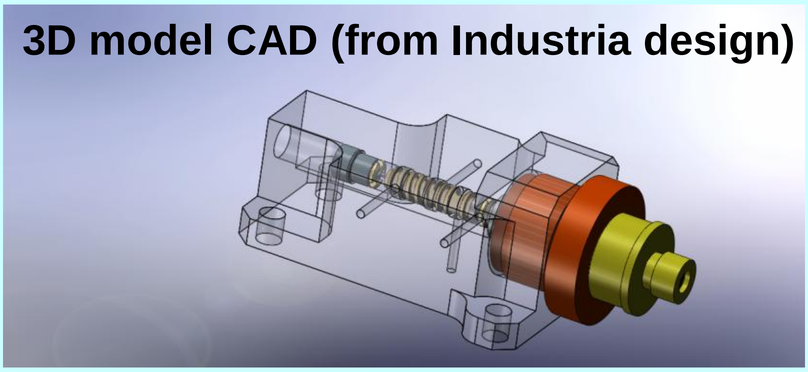

Figure 12 The micro valve CAD model from Industria

2.5.3 The way forward

The activity of work package 4 and subsequent evaluation within task 7.6 represents the first detailed investigation aimed at embedded electrical actuation in a high temperature gas turbine environment. Although the fuel staging valves could not be completed within the ADVACT timescales, initial results are encouraging and could be considered for future programmes.

Considerable further development has followed the ADVACT activity and is building on the work towards providing significant technology for a number of applications both within the gas turbine and other industries. These include

The Environmentally Friendly Engine (EFE) EU framework 6 programme where a design study has been completed into electromagnetic turbine tip clearance control, followed by building and testing of an actuator in a test chamber.

The ADvanced Electrical Machines Materials (ADEMM) UK government funded programme which made a more extensive fundamental investigation of higher temperature coils. Testing of coils with an expected capability of operating at 450^0C for long periods is currently underway.

High temperature Environment AcTuators (HEAT), a R-R Private venture programme investigating embedded electromagnetic systems within the pressure vessel of a civil Pressurised Water Reactor (PWR) nuclear reactor.

Other programmes are also investigating further temperature improvements, high temperature electric motors and generators, active magnetic bearings and high voltage / high temperature cabling.

2.6 Vibration control systems

2.6.1 Background

Control of engine rotor vibration remains a major reliability facet of engine design and is a significant cost in engine manufacture and operation.

Low vibration is essential to ensure long life of many engine components such as the rotor bearings and the engine external systems. At higher levels of response, excessive rotor vibration causes significant wear of the casing liners, increasing the blade tip to casing clearances leading to loss of engine efficiency and increase in CO_2 emissions. Transmission of vibration into the airframe is also increasingly becoming a concern as airframers strive to improve the cabin environment for the comfort of the passengers.

Vibration control in most engines is achieved through squeeze-film dampers (SFD's). These are very easy to fit within the engine at the bearings, and are very effective in controlling low to moderate levels of vibration. They are however passive devices that must be designed as a compromise for various engine running conditions and they often allow little scope for tuning their performance to cope with special conditions.

Electrical actuation systems offer the attractions of improved control, though at the expense of some increase in engine system complexity and the introduction of new concerns over the failsafe behaviour.

Active magnetic bearings offer the widest scope for optimising the rotordynamic behaviour of an engine. They replace the conventional rolling element bearings with magnetic forces to centre the rotor orbit, and by providing stiffness forces (i.e. forces in phase with the orbit) they can modify the rotor critical speeds to keep them away from the running condition.

There are significant disadvantages however. Firstly, the shaft weight must be supported by the electromagnets which adds significant weight and requires an additional mechanical system to provide fail safe operation in the event of electrical system malfunction.

In contrast, an AMD uses a conventional rolling element bearing to support the main weight of the shaft, with the electromagnetic system just controlling the rotordynamics. This leads to a much smaller and lighter system with much less problematical failure modes. It does however require the retention of the oil system.

2.6.2 Progress

Given that the maximum force output from an electromagnetic actuator is largely dependent on its mass, for aircraft engine applications it is essential to make the best use of the actuator force available and so keep the actuator as light as possible. It had previously been noted, from the basic physics of vibration systems, that directing the actuator force towards damping, rather than a combination of stiffness and damping, might achieve the most effective results for a given actuator mass.

The concept developed by Polytechnic University of Turin, requires modifications near the rotor bearings and supports only, and as these are the low radius parts of the rotor, the system can be relatively compact and light in weight. The few new mechanical features are similar to those in existing engines with squeeze-film bearings, so the new concepts and their effects are easily understood. The system is tunable, both electrically and mechanically. Some compromise on rotor support stiffness and hence rotor critical speeds may be involved, but again this is typical of squeeze-film damper design too.

The effectiveness of the Turin concept was well demonstrated in ADVACT WP6 by means of theoretical studies and a laboratory scale Rotordynamics Test Rig (RTR). The test rig (Figure 13) also enabled good demonstration that the controlling electronics is effective and readily feasible to make.

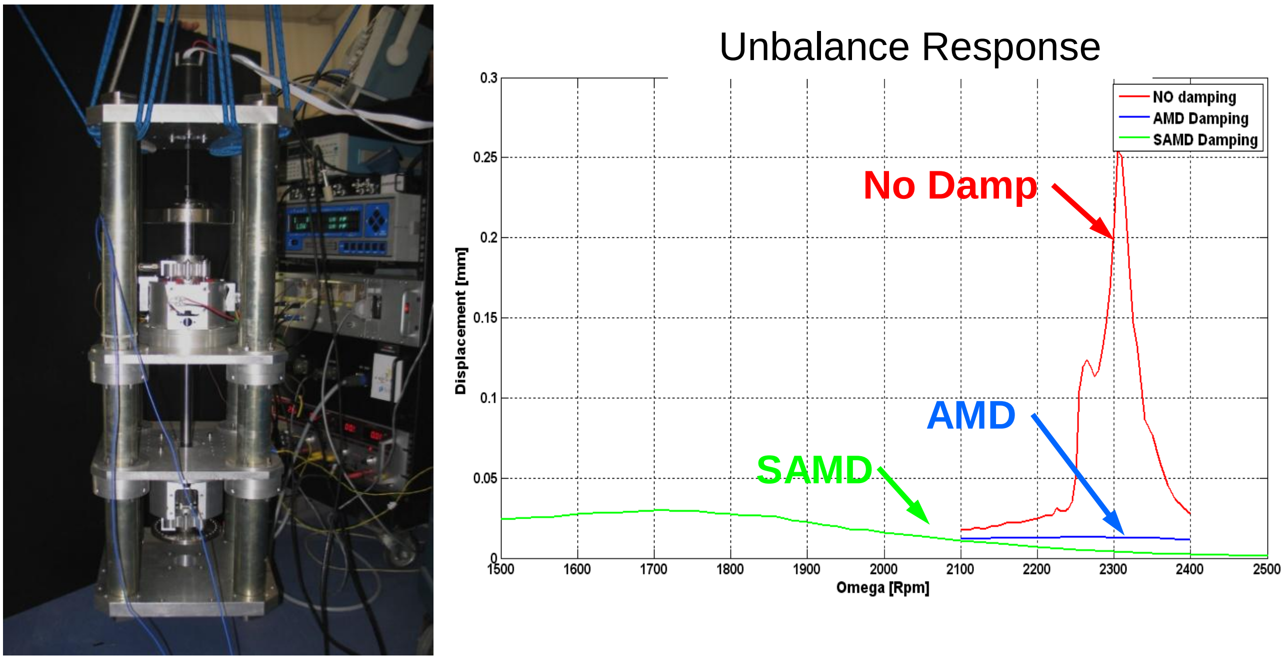

Figure 13 Rotordynamics / AMD demonstration rig and control results

In WP 10 the participants performed theoretical studies using representative Whole Engine structural models to predict the response of two different engine designs with active electromagnetic dampers. In both cases the dampers were shown to be effective, and their performance was similar to that of conventional squeeze-film bearings at their design point. The performance was of course much more readily tuneable for different operating conditions. A potential application configuration is shown in Figure 14.

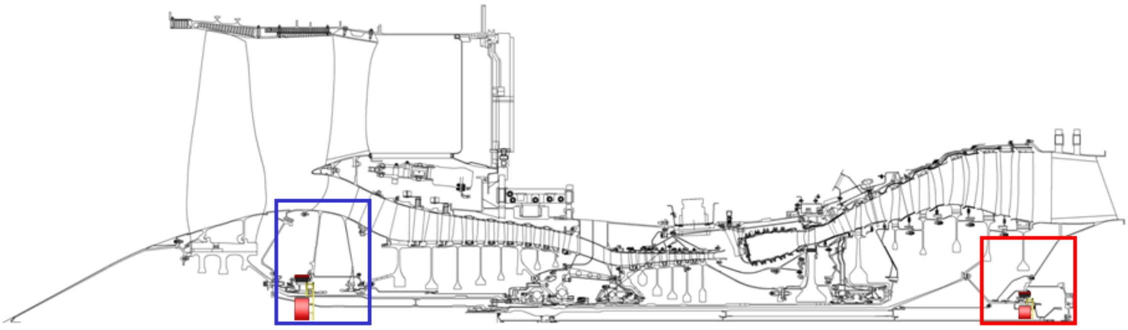

Figure 14 Sketch of the installation of AMDs on LP supporting bearing of Trent500 engine.

2.6.3 The Way Forward

The priority is to demonstrate the technology on an engine, or at least on an engine sized rotor test rig with realistic simulation of the engine environment, including representative vibration, thermal and oil flow conditions. In addition to the demonstration of damper performance, a most valuable part of such a programme would be considered during the design phase, where the detailed confrontation of the various specific design issues would be a more difficult step than we have been able to complete in ADVACT but obviously an essential one for proving this technology. The high temperature coil technology developed within work package 5 will make a significant contribution to this.

The programme should also encompass the demonstration of further AMD capability, such as control feed-forward to provide unbalance compensation, and a number of other capability extensions that the ADVACT WP6 and WP10 participants are in the process of patenting.

In the longer term, application to specific types of engine project must be envisaged, and the development effort focussed on these.

A possible way to do this would be to combine the damper function with that of other existing and future electrical systems on the engine. Replacing existing systems would directly mitigate the added weight and cost of the AMD's, while in future it may be possible to offer AMD's as part of more comprehensive packages of engine vibration control and monitoring.

3 DISSEMINATION AND USE

3.1 Exploitable knowledge and its Use

Overview table

No	Exploitable Knowledge (description)	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & Other Partner(s) involved
1	Actuator Device	Any blade configuration	Aerospace	>2010	Patent application under consideration	MTU, IEMN
2	SMA Surface Coating	Deformable blade	Aerospace	> 2010	Patent application under consideration	MTU
3	Large section, repeatable SMA materials	Variable area nozzle	Aerospace	>2010	None	Rolls-Royce
4	Design methods SMA structures	Variable area nozzle	Aerospace	>2010	None	Rolls-Royce
5	Active Magnetic Damper or Electromechanical Damper	Damped bearing with tuning capability	1 Aerospace 2. Industrial 3. Naval 4. Automotive (commercial vehicles)	> 2010	TBD	AVIO S.P.A & CSPP-LIM Politecnico di Torino
6	High temperature electrical machine windings	High temperature motor/generator/actuation	Aerospace Marine	>2010	None	Rolls-Royce
7	ElectroMechanical Engine Mount	Vibration Isolation	Automotive: power-train Industrial Machining Aeronautical Aerospace	> 2010	None	CSPP-LIM: Polito
8	ElectroMechanical Damper (EMD)	Gas turbine engine rotor vibration control	Automotive: power-train Industrial machining Aeronautical Aerospace Power generation Naval Propulsion	> 2010	2 patent applications made	CSPP-LIM: Polito R-R

3.2 Dissemination of knowledge

The dissemination activities section should include past and future activities and will normally be in the form of a table maintained by the coordinator or any other person charged with controlling the dissemination activities**.**

Overview table

No	Planned/ actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
1	2005/6	Internal Avio Conference	Industry	Italy	20	Avio/Polito
2	2005/6	Conference	Research	International	200	Polito
3	Nov 2005	Exhibition	Industry	International	2,500	Rolls-Royce, Polito
4	June 2006	Conference	Industry	International	1,000	ADVACT partners
5	Mar 2006	Conference	Industry/Academia	International	600	Rolls-Royce
6	2007	Conference	Academia	International	NA	Cranfield, Snecma, Onera IEMN, Rolls-Royce
7	2006	Publications	Research	International	NA	Polito
8	2008	conference	Industry/Academia	International	>2,000	RR, Snecma and MTU
9	2008	conference	Industry/Academia	International	>2,000	RR, MTU, Onera and Cambridge
10	2008	Conference	Industry/Academia	International	>500	Polito
11	2009	Conference	Industry/Academia	International	>500	CNRS
12	2009	Conference	Industry/Academia	International	>500	Cambridge, Snecma

1) A conference, (internal to AVIO)

2) Conferences:

- AIAS Conference (http://aias05.mecc.polimi.it/) Milan, Italy Sept. 14th-17th 2005
  Polito presented a paper concerning the Electromagnetic Damping (EMD):
  "Eddy current damping of flexible structures using electromagnets" by Amati, Carabelli, Macchi, Silvagni, Tonoli
- PEMD Conference (http://conferences.iee.org/pemd/Welcome.html) Dublin, Ireland, April 4th-6th, 2006
  Polito presented a paper concerning the modelling of electromagnetic actuators:
  "2D and 3D Modelling of U-shape Electromechanical Actuators for Mechatronic Applications" by Canova, Cavalli, Macchi, Silvagni, Visconti
- FMD Conference (http://www.lut.fi/kote/teras/fmd2006ins.html), Lappeenrantaan, Finland, June 13th-14th 2006
  Polito presented an invited paper concerning the trade-off analysis on various damping techniques:
  "Vibration Control of Rotors: Trade-Off between Active, SemiActive and Passive Solutions" by Genta, Amati, Carabelli, Macchi, Nicolotti, Silvagni, Tonoli, Visconti
- ESDA-ASME Conference (http://www.asmeconferences.org/esda06/) , Torino, Italy, July 4th– 7th, 2006
  Polito presented a paper concerning the transformer eddy current dampers:

“Transformer eddy current dampers in rotating machines vibration control” by Amati, Carabelli, Macchi, Silvagni, Tonoli

- ISMB-10 (http://www.ismb10.org/) Martigny, Swiss, August 21st -23rd 2006
  Polito presented a paper concerning the trade-off analysis on various damping devices:
  “More electric aero engines tradeoff between different electromagnetic dampers and supports” by Amati, Carabelli, Genta, Macchi, Silvagni, Tonoli
- IFTOMM-Rotordynamics (http://iftomm-rotordynamics2006.mdmt.tuwien.ac.at/wiki/index.php/Main_Page), Vienna, Austria, September 25th-28th 2006
  Polito presented a paper concerning the semi-active damping devices for rotordynamics applications:
  “Semi-Active Vibration Dampers For The Dynamic Control Of Rotors” by Genta, Amati, Tonoli, Silvagni, Macchi, Visconti, Carabelli
- AIAA 4th Flow Control Conference (http://www.aiaa.org/agenda.cfm?lumeetingid=1819), Seattle, USA, Seattle, 23th-26th June 2008
  AdvAct partners presented a paper on AdvAct project:
  “ADVanced ACTuation for Future Gas Turbine Engines (ADVACT)” by Buffone, Webster, Kyritsis, Evanno, Hiller, Pernod, Chanez, Garnier, Wakelam, Evans, Tonoli, Silvagni
  The new version of the ADVACT video was released and presented at this conference.
- VIRM9 (http://www.imeche.org/events/virm9), Exeter, United Kingdom, September 8th-10th 2008
  Polito and Roll-Royce presented a paper concerning the application of EMDs on real engines:
  “Design Of ElectroMagnetic Damper For Aero-Engine Applications Rotors” by Tonoli, Silvagni, Amati, Staples, Karpenko

3) Exhibitions:

- Communicating European Research 2005 International Conference (http://europa.eu.int/comm/research/conferences/2005/cer2005/index_en.html, Brussels, Belgium, Nov. 14th -15th 2005
  Polito and Roll-Royce presented a stand

4) Publications:

- Paper on Journal of Dynamic Systems, Measurement, and Control (http://scitation.aip.org/ASMEJournals/DynamicSys/)
  A. Tonoli, N. Amati, M. Silvagni, Transformer eddy current dampers for the vibration control, Journal of Dynamic Systems, Measurement, and Control, May 2008, Vol. 130 / 031010-1
- To be submitted to JOURNAL OF ENGINEERING FOR GAS TURBINES AND POWER (http://catalog.asme.org/Journals/PrintOnlineProduct/JOURNAL_GAS_TURBINES_POWER.cfm) a paper with Rolls Royce on the application of EMDs on real engines.
- Further publication on:
  Journal of Sound and Vibration (http://www.elsevier.com/wps/find/journaldescription.cws_home/622899/description#description)
  IEEE-ASME Transactions on Mechatronics (http://www.ieee-asme-mechatronics.org/)

4 PROJECT LOGO

ADVACT
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