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By Sir William Hawthorne, F.R.S., H. Cohen and A. R. Howell

The significant contribution to engineering science made by Hayne Constant, especially in the field of aircraft propulsion, was foreshadowed by his boyhood interest in invention and technology. Born at Gravesend, Kent, on 26 September 1904, he was the second son of a family of six children and his early childhood was spent at Folkestone where his father was a dental surgeon. From the age of eleven he was educated at various schools, first at King's College Choir School, Cambridge, then King's School, Canterbury, the Technical Institute, Folkestone, and Sir Roger Manwood's School, Sandwich. In his Higher School Examinations he obtained distinctions in mathematics and physics and was awarded a State Scholarship. He went up to Cambridge when 20 years old in October 1924, having obtained an Open Exhibition at Queens' College, and pursued a course commonly taken by the more gifted students, in that he first of all took Part I of the Mathematical Tripos and then proceeded to take the Mechanical Sciences Tripos in the following two years. His thoroughness and enthusiasm, reflected especially in his meticulous notes, resulted in First Class Honours and he was made a Scholar of his College. He took little if any part in College sporting activities but was a keen walker and took his exercise in this way around the byways of the Cambridgeshire fens, no doubt deep in thought about his current academic problems—a characteristic which revealed itself in his later life as he was well known for much pacing up and down of his office as he considered the problems of gas turbine development which occupied the major part of his active career.

After taking his degree, Constant stayed at Cambridge for a post-graduate year 1927–28 which he used to do research on the torsional vibration of crankshafts for a Panel of the Engine Sub-Committee of the Aeronautical Research Committee. The results of this work were published in R. & M. 1201 (October 1928) under the title 'On the stiffness of crankshafts'.

On leaving Cambridge he went to the Royal Aircraft Establishment, Farnborough, in July 1928 and for the next 6 years worked in the Engine Department on a number of different projects. In addition to continuing with his interests in the problem of engine and aircraft vibration, he made investigations into exhaust-driven superchargers, dynamometer hubs, carburetters and engine operation

on weak mixtures. During these formative years he acquired something of a reputation among his colleagues for an attitude of arrogance and superiority. Intolerant of pomposity and humbug, he was always single minded and his anxiety 'to get on with the job' forced him to take the sort of steps which lesser men might well have avoided. For instance, it is recalled that, while still a relatively raw recruit in the Flight Section at R.A.E. in which the pace of research is notoriously slow because of the influence of aircraft serviceability, weather conditions, etc., he complained to his chief that there was practically nothing to do. Instead of being rebuked for his impatience, he was transferred to work on stiffness of aero engine crankshafts, with which he had already had some experience at Cambridge. In this activity he was much happier and collaborated well in the general work of that group. He still, however, had the reputation of a supercilious manner in discussion and usually non-plussed his fellow debater by answering any statements of apparent fact by the one word 'Why ?', thereby always putting the ball back into the other man's court. One day, no doubt feeling more than usually depressed with the work and wanting something more exciting, he nearly caused the death from apoplexy of the group head by asking him: 'When are we going to stop frigging about with torsional vibration ?'

At this time Constant did some good and original work on the first practical attempt to measure aircraft vibration in its natural modes and when forced by engine dynamics. He tested and analysed the results from a biplane suspended upside down and vibrated by rotating vibrators mounted in the aircraft. His report virtually initiated practical work in this field. For a paper on aircraft vibration, reported in the journal of the Royal Aeronautical Society of March 1932, he was awarded the Busk Memorial Prize.

The gas turbine

In 1934 Constant decided to try his hand at university teaching and left Farnborough to become a lecturer at Imperial College but, after two years in this activity, he decided that its repetitive nature was not to his liking and he returned to R.A.E. where, in July 1936, he was put in charge of the Supercharger Section of the Engine Department. This 'Supercharger Section' was, in reality, the Internal Combustion Turbine Section although the name was retained for some years for camouflage reasons.

Perhaps one reason why he returned to the Royal Aircraft Establishment was a conversation with Mr (later Sir Henry) Tizard who suggested that a great future for aircraft propulsion might well be in the gas turbine engine. In 1930 a Panel of the Aeronautical Research Council under the chairmanship of Tizard had lukewarmly recommended some experimental work, but little work had been done. Constant certainly attributed his return to R.A.E. to Tizard's encouragement to work on gas turbine engines. He was also greatly influenced by the then Head of the Engine Department, Dr A. A. Griffith, who had put forward as early as 1928 some very fundamental and revolutionary ideas concerning the design of axial flow compressors and turbines which would be the basic component of the type of power plant envisaged. At about this time, of course,

Flight-Lieutenant (now Air Commodore Sir Frank) Whittle was actively engaged in the development of his gas turbine which had the essential difference of employing a centrifugal compressor in comparison with the axial compressor which was the basis of the ideas of Griffith. This exciting new field of research was ideally suited to Constant's temperament and it became his all-absorbing interest. Within a short time he had prepared a report on the prospects of the gas turbine, R.A.E. Note E3546, March 1937, entitled 'The internal combustion turbine as a power plant for aircraft'. In this he concluded:

> 'In the light of existing knowledge an internal combustion turbine could be constructed using only types of components which have been proved by past experience. The performance of such a turbine, on the basis of specific weight and economy would be better than or substantially equal to that of the best modern water-cooled petrol engine, except when cruising at comparatively low altitudes.
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> 'Under take-off conditions both its specific weight and specific fuel consumption would be less than that of the petrol engine. At an altitude of some 20 000 ft its specific weight and specific consumption would be similar to that of a petrol engine operating under economical cruising conditions. Above this altitude both its specific weight and fuel consumption would be less than that of the petrol engine. Below this altitude its specific consumption would be greater and its specific weight less than that of the petrol engine.
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> 'Possible developments in materials and air compressor design foreshadowed by recent research suggest the possibility of constructing in the near future an I.C.T. whose specific weight would be less than that of any internal combustion engine at present in production under all conditions of flight and whose specific fuel consumption would be less than that of any spark ignition engine and comparable with that of any compression ignition engine, under all conditions of flight.
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> 'The simplicity of the I.C.T. with its freedom from the inherent complications of the reciprocating engine has made it the dream of many engineers. The very magnitude of the advantages which it has to offer, associated with the repeated failures to achieve a practicable design, have given the impression that the I.C.T. is merely a convenient medium on which to work off the surplus energy of imaginative inventors. In fact, however, the same principles and the same practical experience as have in the past predicted the performance of machines of far more novel design can be applied to determine the probable success or failure of the internal combustion turbine.'

This report was discussed by the Engine Sub-Committee of the A.R.C. on 16 March 1937 under the chairmanship of Sir Henry Tizard and its advocacy was so persuasive that the Sub-Committee declared itself in favour of a vigorous policy of development, although it should be noted that they were then thinking in terms of a turbine-driven propeller rather than pure jet propulsion. At the same meeting similar support was also given to the Whittle jet propulsion scheme

and there was no doubt in Constant's mind that it was Tizard's imagination and enthusiasm that provided the drive during that critical time for the future of gas turbine work in this country.

In the meantime R.A.E. had asked for and obtained authority to build an axial flow compressor intended as a supercharger for a piston engine. This machine, later called 'Anne', was designed by Constant and had eight stages of free vortex blading. It was a small 6-in. tip diameter unit with a tip speed of 750 ft/s. The unit was completed early in 1938 and stripped its blading 30 seconds after starting owing to a faulty design of an oil seal which caused overheating of one of the disks. It was modified, rebuilt and run again towards the end of 1938 and helped to give a clearer insight into many of the problems of multi-stage compressors. Its life was ended by a German bomb on 16 August 1940.

Various gas turbine schemes were considered by Constant during 1936–37 working virtually alone with some help from other sections in the R.A.E. The incentive given to Constant's work by the previously mentioned approval of the A.R.C. resulted in his being able to gather together a small group of helpers, which included specialists in the field of compressor and turbine aerodynamics, performance and design, combustion and so forth. The number of personnel steadily increased until what was once the small I.C.T. section became, in 1941, the Turbine Division of the Engine Department. At this juncture Constant became the Head of the Engine Department and Dr (now Sir William) Hawthorne was put in charge of the Division.

R.A.E. collaboration with Metropolitan-Vickers started with preliminary discussions during the latter half of 1937 and in January 1938 the firm commenced work on a contract from the Ministry to produce an internal combustion turbine for bench testing to demonstrate the possibility of this type of power plant being used in aircraft. Other firms with whom Constant had connexions, particularly in relation to his work on axial compressors, were Fraser and Chalmers, Bristol (Engines), C. A. Parsons and Armstrong Siddeley Motors. Much of this collaboration is covered in his lecture to the Institution of Mechanical Engineers (*Proceedings*, 1945, vol. 153) on 'The early history of the axial type gas turbine engine'.

Materials and their properties exercised much of his thoughts during the early days, but High Duty Alloys and Firth-Vickers were able to meet the immediate requirements for compressor and turbine components respectively. However, this did not stop him from holding discussions with the representatives of the refractory trade on the chances of making complete bladed disk wheels of ceramic or refractory materials and with the plastics industry to pursue his idea of using such material for axial compressor blades, although he ultimately found no reasons for going ahead with any of them. Combustion, because of the need for high intensity and low weight chambers, was made the subject of experiments by him in 1936 and then actively pursued by other members of the team who later joined him.

He first met Whittle in August 1937 and during that month saw one of the early runs of the first jet propulsion gas turbine at the B.T.H. works at Rugby.

In March 1938 the Ministry placed a contract with Power Jets for the development of the Whittle engine with centrifugal compressor. From then onwards there was close collaboration between Whittle and Constant. They did not always agree on the best solutions to various problems but they held one another in high respect. Such rivalry as existed was not between their personalities but between their 'centrifugal' and 'axial' teams and supporters.

Returning to the early gas turbine schemes for propeller propulsion, the 1937 paper previously referred to envisaged the possibility of an engine (scheme A) with a two-stage centrifugal compressor on a single shaft to give a pressure ratio of 6.0, and of a more advanced engine (scheme B) with two axial compressors on separate shafts with a pressure ratio of 8.0. Because of the increasing confidence in the practicability of multi-stage axial compressors, partly due to Brown Boveri experience of them, the original proposal (scheme A) was abandoned, all effort being then concentrated on those schemes using axial compressors. Constant firmly believed that the axial type could give higher efficiency combined with a lower frontal area and less bulk.

Many 'B' schemes with two axial compressors were looked at but with the overall pressure ratio reduced to 5.0. The final arrangement agreed with Metropolitan-Vickers was the B10 of 2000 h.p. to avoid the mechanical difficulties of concentric shafts. The B10 engine had its components dispersed. The price paid for this mechanical simplicity was a flow path for the working fluid which involved a great number of volutes and corners and their attendant high aerodynamic losses. Only the HP part of the B10 scheme was built and run and, ignoring the volute losses, this unit performed well aerodynamically and mechanically when it was tested at the firm in 1940. In an internal paper Constant wrote: 'While it [the HP part] was being built, Howell [one of his team] checked up on volute losses and we thanked God that we had not built the complete plant!'

After this experience with the B10, Constant stuck whenever possible to 'straight-through' engines and the subsequent 'D' schemes were of this form. The first of these was submitted to Metropolitan-Vickers, the drawing being dated 25 October 1938. It had two concentric shafts and, if the power turbine was replaced by a jet, it would be of the same general form as the present-day Olympus engine in the Concorde supersonic aircraft. The pressure ratio aimed for was 6.0. Again, perhaps rightly at the time, the firm and he boggled at the idea of two concentric shafts and the final version, the D11 (crystallized in August 1939), had a single shaft with a pressure ratio of 5.0. Parts of it were built and tested but it was finally abandoned because of the war and the greater need for jet propulsion engines.

An important problem associated with this type of machine was the stalling at the lower speeds of the front stages of high pressure-ratio axial compressors. Constant was well aware of this and its solution, as instanced by the following extract from a letter to the firm on 14 December 1938 about the 'D' schemes:

> 'In the earlier stages of this work, we objected to your suggestion that all the compression should be done in a single unit because we considered

it appeared unlikely that we could obtain pressure ratios as high as 6 : 1 without using two units in series.

'The results referred to above, considered in conjunction with the possibilities of bleeding of air or rotating some stator blades at low speeds, and utilisation of the dynamic head due to the motion of the aircraft, provide a distinct possibility of obtaining in a single unit pressure ratios as high as 6 : 1.'

The problem of stalling loomed so large at that time that the R.A.E. bought a Brown Boveri industrial gas turbine with an axial compressor and performed a large series of tests, particularly starting tests, to determine the conditions in which the compressor would stall and become unstalled. During these tests the combustion chamber became overheated and developed a bulge in its outer skin. Later the compressor blades failed, perhaps owing to vibration when stalled, and were replaced by blades thickened at their roots.

Jet propulsion

Before 1939 R.A.E. had always considered the propeller to be the better application of the gas turbine in aircraft although ducted fans were also regarded with some favour. The pure jet was thought to be applicable only to short-range high-altitude fighter aircraft. However, the approach of war settled the issue, and in September 1939 Constant suggested to Power Jets that a jet propulsion engine should be constructed on the basis of the D11 design, the power turbine being omitted. This came to nothing and design work began on new 'straight-through' axial jet propulsion engines, the 'F' schemes. The following paragraph is taken from Constant's paper on the early history (*Proc. Inst. Mech. Engrs*, 1945, vol. 153):

'My original conception of the F type jet propulsion engine is shown in Figure 20. This design, known as the F1, was produced in December 1939 and it provided for a unit giving 2150 lb static thrust, a pressure ratio of 4 : 1, a maximum temperature of 800 °C (1472 °F) with a mass flow of 38.0 lb per sec. The design speed was 9450 r.p.m., the overall diameter 27 in. and the length 7 ft 9½ in. The compressor was of nine stages with a rotor having a disk wheel construction; the combustion chamber was of annular straight-through layout; the compressor was driven by a single-stage water-cooled turbine; provision was to be made for control of the compressor boundary layers by air bleeds and bearing lubrication was by oil bath with no circulating system.'

The drawing of this engine was dated 7 December 1939 but it was not strictly the first design and was in fact a 1.2 times linear scale version of an engine of 1500 lb thrust, the drawing of which was dated 3 November 1939. It had been hoped to get the engine manufactured as a joint effort by Power Jets and R.A.E. but the work was taken over in 1940 by Metropolitan-Vickers, becoming the F2, the first British axial jet propulsion engine, and culminating in a line of development leading through the Beryl engine and the F9 to the Armstrong Siddeley Sapphire engine. Constant naturally kept a great personal interest in

these engines. He never returned to supporting propeller gas turbine engines and believed firmly in jet propulsion in either the pure or ducted fan form. Although Constant concerned himself with all aspects of the work, perhaps his most significant contribution at this stage was in connexion with the compressor design, he having already evolved the formula for the flow angle leaving a row of compressor blades which became known as 'Constant's deviation rule'.

A particular problem which occupied much of Constant's thoughts around this time was what he himself called 'the nightmare of thermal distortion'. In his paper on the early history he says:

> 'I recall very well a period in 1938 when the difficulties likely to be encountered by differential thermal expansion and distortion overshadowed my thoughts like a nightmare. It will, I think, be agreed that there was some justification for this foreboding, for an engine of the size we were contemplating would increase in length by about one inch when hot. Again, the blade clearances at which we wished to operate would have been completely taken up by a change of only 50 deg. C (90 deg. F) in the local temperature of certain parts of the engine. Further, the degree to which the materials used could flow plastically and thus relieve thermal stresses while avoiding permanent distortion was not known. For these reasons very considerable thought was given to the problem of reducing relative expansion as much as possible. Many schemes—some of terrifying complexity—were considered. . . .'

History shows that all these difficulties were ultimately overcome and the successful outcome of Constant's scheme for a straight-through jet propulsion engine using an axial flow compressor was probably the pinnacle of his individual contribution to modern-day aircraft. This machine was undoubtedly the forebear of the great majority of jet propulsion engines powering the world's aircraft today. It was this unerring conviction that the jet engine would ultimately oust the piston engine in all except the smallest power ranges which probably led him to establish the Gas Turbine Division of the Engine Department of R.A.E. in a new but neighbouring site at Pyestock. At this new site facilities for all aspects of gas turbine research were rapidly built up with an accompanying increase in the size of the team of scientists and engineers.

During this time Constant had to run all the aero-engine activities of the R.A.E. including its active flight section. Much work was done on radiators and oil coolers, water injection, superchargers, exhaust flame damping and carburetion. But his regular discussions with the Head of the Gas Turbine Division showed not only his major interest, but also his talent for the analysis of engineering problems and for the direction of research. He formulated penetrating questions in response to which he demanded rigorous and realistic answers. He persuaded the Ministry that all projects for gas turbine engines should be 'vetted' by the R.A.E. Division and thereby created in the Division a body of knowledge, expanded by its own project studies and experimental research, which provided much of the technical basis for the designs of the aircraft gas turbines which several firms began to evolve. During this period tensions

inevitably developed between the firms, the Ministry and the Division, but Constant's almost Olympian demand for logic and consistency coupled with his faith in the future of the gas turbine engine greatly strengthened the morale of the Division in which many young men felt uneasy about the value of their contribution to the war effort. Although his questions were penetrating and could frequently make their recipients uneasy, Constant never descended to a personal level in any of his discussions and this characteristic was both a strength and a weakness. His wartime staff regarded him as both fair and aloof, but gave him their confidence. His superiors may well have been distressed by his self contained quality which did nothing to soften the edge of a mind delighting in logical argument.

A feature of Constant's interest in the creation of the Gas Turbine Division was the attention he paid to the recruitment and development of its staff. He read all of its output and formed sound judgements of its capabilities. When he had formulated an opinion of someone's work he then accepted, supported and used it in all his debates with the firms and the Ministry. When the Aeronautical Research Council visited Pyestock in 1943 Constant insisted that its staff made presentations not only of its current work but also of the history of the R.A.E. work for most of which he had been responsible.

In 1944 there was a momentous change in the activities of the R.A.E. Gas Turbine Division at Pyestock when it was decided to merge the team with Whittle's organization, Power Jets, into a Government-owned company called Power Jets (R & D) Limited. Almost certainly this merger was not entirely to Constant's liking as it resulted in many upsets and alterations to his plans and aspirations. After two years, in 1946, a further change was made and what had by now become a large complex at Pyestock became the National Gas Turbine Establishment with Constant as Deputy Director. Two years later he became Director of the Establishment and proceeded even further to widen its activities so that it became the foremost centre of gas turbine research in the world. He remained as Director until 1958 and then, with considerable reluctance, left to become Scientific Adviser to the Air Ministry and Chief Scientist (R.A.F.), Ministry of Defence. To all who met him in these later phases of his career, it was clear that he was not very happy in the Whitehall atmosphere and that he would much have preferred to remain in research and inventive activities.

Other activities and honours

The success of Constant's work brought him many honours. In 1948 he was made a Fellow of the Royal Society; in 1951 he received the decoration of the C.B.E. and in 1958 a further decoration of C.B. From the Institution of Mechanical Engineers he received in 1948 the James Clayton Prize for his work on the development of turbo-jet engines and in 1963 the Gold Medal of The Royal Aeronautical Society in recognition of his work on the development of the gas turbine.

As much of Constant's work was always shrouded by a mantle of secrecy his publications were not particularly extensive. Nevertheless he was the author of some 23 papers and also 10 patent specifications. With regard to the latter, the

number could have been very much greater but his primary interest was always in the inventions themselves and not in patents and possible consequent monetary gain. He was the instigator of a unique series of lectures given by himself and his colleagues to the Institution of Mechanical Engineers (*Proc. Instn mech. Engrs*, vol. 153, 1945; vol. 159, 1948; and vol. 163, 1950) which presented to the profession a full and intriguing account of much of the research and development resulting in the successful outcome of a practical and revolutionary power plant for aircraft propulsion. He also gave about 20 lectures, speeches and broadcasts, but his only published book was a small and unpretentious volume entitled *Gas turbines and their problems* which appeared in 1948 and was revised and enlarged in 1953. This small book was clearly an attempt to bring before as wide a public as possible his enthusiasm for what to him was undoubtedly a form of prime mover having unrivalled prospects. As he says in the Introduction, '. . . Certain it is that no prime mover has started its career with such brilliant promise'. He probably cherished the notion that his carefully described ideas would encourage those of his readers embarking on scientific and engineering careers to join in the development of the gas turbine for a wide variety of applications in addition to that of aircraft propulsion. In certain respects the book bears a close similarity to those which he himself enjoyed in his youth.

As a personality he was rather reserved and did not make friends easily but among those few who knew him well many tributes to his personal qualities have been ungrudgingly paid. He was a man of austere habit and thought who shrank in natural distaste from any triviality and there were many who found him cold or at least difficult to know and indeed, though never forbidding, he often gave an impression of deep reserve. As a profoundly polite man he could not respond to, or perhaps simply did not comprehend, anything which to him was an intrusion upon privacy. But those ideas and pursuits which were for him natural to share, he did share, and shared with a most attractive gaiety and simplicity. The brilliant successes arising directly from his ideas, encouragement and technical judgements in the aircraft gas turbine field were obvious to all who worked with him. He had a special gift for decision and for being very single minded in purpose but he nevertheless gave his creative staff great freedom and provided the right environment, initiated discussions, etc. to produce good results. He saw the wood as well as the trees; no amount of detailed and penetrating technical discussion on particular issues would blur his overall balanced view or dull his purposeful sense of direction. He spoke precisely and economically when others were verbose.

In addition to the technical work of the N.G.T.E., with whose foundation and build-up he was so closely associated, he took a special interest in the welfare of its staff, fostering their sports club activities, and, at a time when housing was a big problem during and after the war, he did everything he could and solved many problems.

His relaxations were many but it was his characteristic to concentrate upon them, to move on after a clean break to new interests and not to persist in any

one or to return to it. So it was for example with tennis, with amateur dramatics, with high-power motor cycles, sailing and boat-building, the design of his unique bachelor's house and the great American stage musicals of the fifties. In these, among others in turn, he took a zestful enjoyment, understood and savoured them keenly then closed the chapter and passed on. It is among those with whom he shared, either in his professional life, moments of appreciation of some clarification of thought or some new idea or some polished achievement, or outside it in his appreciation of other keen enjoyments that one finds the full realization of an attractive and rare personality. At these times all distinctions of age, experience, status and renown which he himself never demanded vanished also for lesser participants.

On his retirement he lived in a bungalow built to his own specification at Hindhead, Surrey, which, alas, he did not enjoy for very long for he died at the early age of 63 on 12 January 1968.

The photograph is by W. Stoneman (copyright G. Argent).

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