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THE ROLE OF GIUSEPPE GABRIELLI IN THE EVOLUTION OF AEROSPATIAL DESIGN AND HIS INFLUENCE ON RESEARCH AT THE POLITECNICO DI TORINO

Summary

Knowledge in the times of the Wright brothers and above all the contribution to the philosophy of design are taken as the starting point of an evolution process in which new problems, new concepts, new goals in facts of speed, transport, capability, endurance, handling qualities**,** and so on have come together. Giuseppe Gabrielli fully fits into this scenario and as a leading actor in this evolution, with a pregnant vision of aeronautical engineering**,** which he saw as a single body of knowledge that included doctrine, design and procedures.

In order to understand the contribution that Gabrielli made to the field of aeronautical knowledge, it is possible to distinguish the following levelsw of interest: industrial strategy, which, as a consequence of the dimensions of our country, from the strategy of a single industry, appears as the determining part of that of the industry of the country itself, philosophy of the design and, last but not least**,** research and scientific knowledge. The actions of Gabrielli, schematically identified in contributions, can be presented according to their chronological order, placing each one on the basis of its moment of greatest intensity, even though there has always been fusion between them in the various stages: the cantilever monoplane wing; the price of speed and the discussion on feasibility; the models, the tests and the dimentionless representation of the physical laws and of the experimental and theoretic results; the technological industrial pursuit through the licenses and the contribution to setting up of a country system, larger than only a Company, in aeronautical technology; the project as a synthesis and result of the mutual interdependence between the components of the system; the importance of safety and reliability for the success of an aeroplane; the necessity of examining the behaviour of the systems in actual working conditions and the behaviour of the structural components in the actual constraint conditions; feasibility and optimisation of the STOL and VTOL aircraft and the spatial activity as a logical extension of aeronautic activities. The importance of each contribution to the various levels will here be examined while the role of the various contributions to the evolution of design way of thinking and the actions that were successful in both the industrial and academic environments will be presented, underlining in particular the activities that are at present being carried out at the Politecnico di Torino, which can be considered as either developments or extensions of the ideas of Gabrielli that cover problems which were explicitly or implicitly anticipated by Gabrielli.

INTRODUCTION

The aviation era began on 17 December, 1903.

Its preparation took place in a dark bicycle shop in Dayton, Ohio, where the brothers Wilbur and Orville Wright worked surrounded by tyres, wheels and pumps, dreaming that man could fly with a machine heavier than air

The Wright brothers showed their first active interest in flying in 1895 when they found out about the experiments that were being carried out in Germany by Otto Lilienthal

However, Lilienthal died in a heap of the wires, rods *and canvas of his glider that a burst of wind had overturned on 9 August 1896 at the age of 48 after having performed 2000 flights.*

They discovered that neither Lilienthal nor the other courageous pioneers of that time had an adequate method to ensure lateral equilibrium of the gliders. Orville then had the idea of making

the incidence of the sections at the edge of the wings variable so as to obtain the necessary force to regain equilibrium.
Their "flying machine" was a biplane with a 12.3 m wing span, a surface of 47.4 m^2 and a weight of 270 kg when empty.
The machine had a 4 cylinder petrol engine with 12 hp at 1020 revolutions that they had built themselves. The engine was connected to two propellers. With a man aboard this machine weighed 340 kg.
That is the physical reason behind the success of the Wright brothers?
It is that their aircraft was the first in the world to have a motility power or more exactly a propulsive power that was sufficient to win over the resistance of the air up to such a velocity to confer to the wings, through "circulation", a lift that is equal to the weight of the machine.
We today know how the origin of "circulation" in the wings and therefore of lift, can be found in viscosity.
However, this theory on the existence of lift did not exist then and in fact after two centuries of mathematical and mathematical physics research, the theory denied that flying was possible.
On the other hand, in the discussions between believers and non believers of flight of the heaviest, the latter put forward an argument that for the authorities who were of the same opinion as the non believers blocked any discussion.
It was Newton's formula of the square of the sine of 1687, given in his famous "principles" for the calculation of the resistance of air on spheres, on cylinders and on cones.
It is truly ironic that the man to whom we owe all the complex of modern mechanics is considered by some to have held up the development of aviation!
The courage and the tenacity of those two young mechanics.
The courage, the perseverance and their ability can only be compared with the greatness of their endeavours.
The aeroplane will always be one of the few truly important inventions to have forged the life and destiny of man.
These words are taken from a letter that Gabrielli wrote on 17 December 1953 on the occasion of the fiftieth anniversary of the first flight. In briefly recalling the spirit of this celebration, which unites the three centennials of the first flight, and of two great masters of the Politecnico di Torino, Ghabrielli and Ferrari and, at the same time projects us in the pregnant vision that Gabrielli had of aeronautical engineering, synthetically seen as a single body of knowledge and capabilities, including doctrine, design and practice, all aspects to which he applied himself, for the final purpose of obtaining the design. He was therefore actively involved in the development of aeronautical engineering way of thinking in all its parts. In a book soon to be published, (1), it is possible to find, amongst other information, a complete scientific bibliography of Gabrielli, to which explicit reference is made because of its completeness.
Aeronautical activity obviously presumes the possession of both the capability to design and to create aeroplanes. The first capability, that of design, is of a technological and scientific nature while the second, that of constructing, is of an industrial nature. As a consequence of our present purposes, we will only briefly deal with the second and as interconnections with the first. Design is the result of a way of thinking or "philosophy" which, in the course of the hundred years that have passed since the first flight took place, has undergone an intense process of evolution and extension of the necessary cultural basis. In the vision of the Wright brothers there were already many fundamental themes on today's way of thinking on design, even though obviously in an embryonic form, and Gabrielli took part in this process of evolution and extension with his aptitude to face the problem in its global extension.
The Wright brothers aircraft had a reserve of fuel that was sufficient for only a few minutes of flight and it developed a maximum speed of about 50 km/h, lifting off the ground by only a few metres. They had however created an aircraft that was in itself a record. To obtain this record they had to exploit the technical knowledge of that time to a maximum, in particular for as far as the lightness

of the structure, the ratio between power and weight of the engine and the performance of the propeller were concerned, obtaining, at the same time, the maximum offered by technology and the minimum to carry out the flight. This problem, basically of feasibility, was well known to the Wright brothers, seeing the efforts that they made to improve the situation, particularly concerned the three previously mentioned problems.
At the same time they were also aware of the fundamental problem of safety, in particular from the structural point of view. In 1900 Wilber Wright wrote to his father: "I'm building my machine so that it can carry 5 times my weight and I'm experimenting on each piece separately. I think that in this way there is no chance that the machine will fail in the air" He was therefore worried about establishing a safety criterion, proposing, if you like, to obtain unit probability of not having failures in the air. At the same time, he adopted the criterion of subjecting, in advance, samples of each component of the structure that was destined for this use to static loads corresponding to the safety criterion, in order to verify the response in consideration of the calculations.
As far as the quality of flight is concerned, the Wright brothers believed, according to several scientists because of their poor knowledge of stability, that the stabilising function should be entrusted to the control system. Deliberately, to have facility in manoeuvring, they built a statistically unstable machine. This fact, together with the lateral control by means of wing distortion, characterised their flights until 1912, giving them remarkable manoeuvring capacity. The Wrights' aircraft were therefore psychologically fatiguing for the pilot and, in a certain sense, more "dangerous". They gave great importance to the problem, as can be seen from a speech that was made in 1901 in which they said: "The obstacles that block our way to success are above all a) relative to the construction of lifting wings, b) relative to the generation and application of the necessary power and c) relative to the balance and piloting of the machine, after it is actually in the air. The first two have already, up to a certain point, been resolved; the third, the difficulty of balancing and piloting, is still the source of different opinions among scientists of the problem of flight. Once this last aspect is resolved, it can be said that the moment of flying machines has arrive". They gave a conspicuous contribution to the solution of the problem, reaching the conclusion that it was necessary to have: a horizontal rudder for longitudinal control, the possibility to curve portions of the wing surfaces and a rudder for lateral control. Many of the solutions they adopted also became dominant for the other pioneers, but not the intrinsic instability. Very soon the European projects that presented the combined and conciliatory characteristics of stability and manoeuvrability, excelled for about twenty years and this conception remained until almost up to 1970, for at least as far as some degrees of freedom are concerned
In the process of extending the culture that is necessary for the design, extensions that are quite natural and which do not take anything away from the importance of the Wright brothers, it is possible to mention in particular the problem of aeroelascicity, structure fatigue and safety deriving from equipment and industrial strategies.

1) GABRIELLI AND HIS ROLE IN AEROSPATIAL ACTIVITIES

Design, with particular reference to the aerospatial field, can in short be considered a complex of operations of very different natures, which, to consider the most important ones, include:

- the utilisation of particular physical phenomena,
- the analysis, through the use of physics and other investigation instruments, of the feasibility of a system, in relation above all to the conditioning imposed by the nature of the properties of the materials that are available and of the environment in which the system must work and to the required degrees of safety,
- the demonstration, through calculations and tests, that the requirements of the design have been satisfied, requirements which have recently highlighted those of reliability,
- the demonstration that the system has reached that degree of safety that collectivity imposes.

The aspect of safety is that which most characterises the design and on which no delays or compromises can be made.
The philosophy of design in the aeronautical field and, in more recent times, in the spatial field has been the subject of an intense and rapid evolution, due to the improvements in performance, to the increases in flight times and in the life times of the machines, not to mention to the physical phenomena and the behaviour of the machines that have resulted from practice of the activity. Giuseppe Gabrielli took part in an important part of this development, contributing to a great extent because of his capability to carry out plans and in a pregnant manner, because of his cleverness in synthesis and doctrine. His vision of aeronautical design soon made him realise the complex of principles, doctrines and notions that make up its foundations, as an organic scientific branch of learning and the Politecnico di Torino made it an obligatory subject for aeronautical engineers, a unique case in the panorama of Italian and foreign universities, at least in the meaning still given today to it at Turin, where the problem of design is faced from the completely general point of view, taking all its aspects into consideration and in its interface with the doctrine, the regulations and the procedures.
The complex and articulated intellectual personality of Gabrielli made his actions develop on many levels, with such complex intersections and distinctions, in the vision that was clear to him and operating, from the necessity of having the capability of design and production well inserted into the international context, participating at an international level.
To schematise and simplify, the following levels can be mentioned:
- industrial strategy, which as a consequence of the size of our country, from the strategy of a single industry appears as a determining part of that of the country,
- philosophy of the design,
- scientific research and knowledge.

The industrial strategy level is here briefly mentioned and within the limit of some fundamental aspects, having relationships that are determinant on the others, which are more of interest, considering the theme we have chosen.
Gabrielli's action*s*, schematically divided into contributions, can be presented according to their chronological order, placing each one in the moment of greatest intensity, even though there has always been osmosis between them.

2) THE CANTILEVER MONOPLANE WING

The first contribution that is here examined concerning the cantilever monoplane wing, is part of the level of the philosophy of design, of that of the industrial strategy and of that of research and scientific knowledge. As far as the first two levels are concerned, he in fact introduced new concepts and new architectures in the solution of the problem of building lifting surfaces and, at the same time, found, for the industrial activity, a way through which the aeroplane could be in a condition to expand in much wider markets, under the form of a means of transport. Gabrielli's contribution to this problem consisted in the fact that our country adopted the metallic solution of the monoplane wing, being able to build aircraft according to his own design and in carrying out experimental studies on the behaviour of such solutions in collaboration with foreign researchers, something that leads us to the third level. An examination of the results that were obtained is surprising because of their clarity and farsightedness: as we are in fact dealing with so-called box wings, it is highlighted that the torsion and bending moments which separately lead to the collapse of the panel are very close and above all that when there are torsion and bending moments together, the limit of collapse can be described by a square interaction law which is identical to that indicated in literature and in standardisation calculation method manuals that are accepted in the case of interaction between normal and shear forces in the problem of elastic instability of flat panels. The first result obviously depends on the fact that the compression failure stress is approximately twice the value of the shear one while the inertial moments of the areas of the torsion section are approximately twice the values of those of bending. This also led him to think that the monoplane wing could be usefully conceived as a tubular structure on which to entrust the primary duties of bearing the forces, with other parts of form. This idea, which is known was soon abandoned, both in consideration of the fact that the box allows greater moments of inertia than the tube, with the same thickness of the overall dimensions, and in consideration of the greater integration between the primary parts and the parts of form.

3) THE PRICE OF SPEED AND THE DISCUSSION ON FEASIBILITY

The experimental statistical investigation *What price speed?*, conducted with professor Von Karman, concerns all the means of transport that are used in the world, destined to cross the atmosphere or seas or even to move along the earth's crust or on sheets of water. It supplied indications of great value and of a general nature on the results of engineering in the field of transport and it gave the consequences, under the form of insuperable limits, of the conditioning that nature opposes to the construction of faster means, due to the effect of gravity, of the nature of water and air, the friction that occurs in practice and even of the properties of the materials found in nature to bear loads of various natures without breaking and also to supply energy through various chemical processes. One of two diagrams is given in figure (1) where the results of the aforementioned investigation carried out by Gabrielli and Von Karman are given. The speeds of the various vehicles in horizontal transfer are given in abscissa while the values of the specific traction force, that is, the ratio between traction and weight, are given in the ordinate. The other diagram, which is not shown here, gives the specific powers in the ordinate. The curves that can be seen are the lower envelopes of the zones occupied by the points that represent the various vehicles of that class; it is clear that the lower value means the best solution. Important conclusions can be drawn from these diagrams on vehicles in general and on aircraft in particular: for example, the specific traction force in airships does not show signs of increasing with the velocity, leading one to think that greater velocities can be obtained without great increases in the necessary power; a similar consideration can be made for helicopters; the vehicles and in general aircraft with dynamic lift are characterised by high values of specific traction force at both high and low velocities with respects to the optimal velocity; this leads to limitations on the development in both directions. Leaving other observations aside, because of space reasons, one cannot but underline the important conclusion - the observation of the existence of a limit line, the lower envelope of the curves of the various categories of vehicles, which shows a technological limit imposed by the materials that are available in nature and by the characteristics of the medium that has to be crossed.

4) MODELS, TESTS AND THE DIMENSIONLESS FORM

The models, tests and the dimensionless form of physical laws and of experimental and theoretical results were, for Gabrielli, from the conceptual point of view, a unitary set, in which, through the instrument of dimensional analysis, to produce clearness in rigor and synthesis in thought, in particular towards design. His analyses concern in general the laws that are at the basis of carrying out tests on models in general. He studied in particular structure similarities and dynamic similarities, which include the majority of tests on models implicated in aeronautical engineering, including for example the tests on anhooking in flight of various bodies, life tests, aeroelastic tests and those on the formation of ice. Figure (2) reports one of the numerous tables he used to explain the implications of the theory of the models in detail: the implications of the geometric, cinematic and material similarities are recalled which, in the approach he preferred, as a whole guarantee dynamic similarity, and which are applied in the same figure to the case of permanent fluid flow**.**
The possibility of putting the interpretations of the physical phenomena in dimensionless form, a passage that is obligatory for theories of models in scale, suggests using the same instrument to reproduce the experimental results, as for example in the problem of the behaviour of riveted joints,

and also theoretical results, such as, for example, in the case of the limits of stability of structures subject to compression, shear or other loading conditions that are likely to cause buckling deformations. Both in the case of experimental results and in the case of theoretical results, the idea is that of adopting dimensionless groups that contain either only design data or only the unknowns of the design, in such a way as to be able to use the representations in a direct way in the design. A diagram is reported in figure (3) that I obtained following the tracks of Gabrielli's formulation that can be used directly in design, which is relative to the behaviour of long and transition circular cylinders subject to axial compression, in the hypothesis that the design data are: the failure load, the length and the radius of the cylinder while the material and its elasticity characteristics are known. Dimensionless parameters can be seen in the abscissas and in the ordinate which only depend on the design data or on the material: with the proposed diagram it is possible to directly obtain, if the failure occurs as a long cylinder or as a transition one, the appropriate ratio between radius and thickness (cylinder design) and a dimentionless parameter with which the failure stress can be obtained. The data on structural behaviour are in fact usually reported in a form that is suitable for the verification operations. The concepts we have underlined therefore concern the level of the design philosophy and that of research and scientific knowledge. The highlighting of the physical significances of the most common dimensionless groups of the physical similarities are of particular interest, in the context of the nature of the equations that make up the mathematical model of the problem under examination.

5) INDUSTRIAL STRATEGY AND IMPACT ON ITALIAN INDUSTRIES

At this point of the analysis of the influence of Gabrielli, a contribution can be inserted at the industrial strategy level, through the start of a technical industrial strategy, through the licenses and a contribution to the growth of Italian industries in aeronautical technologies which had obvious consequences on the development of the capability of our country to take part in the international context. The events that have formed our country had caused a technological gap in the aeronautical field. The choice of producing aircraft under licence with advanced designs, with respect to the technological level that existed, apart from creating work, something that is always useful, led to a kind of technological strategy, both because of the capability to conceive solutions and develop designs and because of the productive capabilities, in the various aspects in which these are articulated, and finally because of the capability of conducting flight tests. The technological strategy in particular concerned the construction of aircraft with sweep-back wings and tail units, and equipped with jet engines. The contribution to the country system can also be seen in the role Gabrielli played in the choices made by the organisations encharged with verifying the design and construction of civil aircraft, for which it was decided to choose American civil regulations as a reference, whose technological level would have been difficult to obtain with only internal forces. This line was adopted by several other countries and, in fact, even the most recent European Regulations, now undertaken in our country instead of national ones, basically adopt the same line. The action that Gabrielli developed in AGARD, the organisation promoted by Von Karman and of which he was the national civil delegate, can be put on the same level. It was from this organisation that our country obtained the maximum possible benefits on the ground concerning technological growth, through a careful choice of the members of the various panels.

6) THE DESIGN AS A SYNTHESIS OF THE INTERDEPENDENCIES

Gabrielli can be thanked for having thought of, from the beginning of his activity and with a restricted number of scientists, the design as synthesis and result of the mutual interdependence between the components of the system, in respect of the operative theme and the regulation prescriptions, a vision which, together with the deep knowledge of the physical phenomena involved in aeronautical design, allowed him to take his place in the international circle of esteemed and appreciated designers. His works are evidence, foreign to his activity as designer, that have generated a long series of aircraft with the initial "G" from the initial of his name:

- on the weight of the wings and of the other parts of the aircraft that the technological level allowed, on the basis of the total weight, of the power of the engine system and of the other general characteristics;
- on the determination of the wing surface and of its aspect ratio, starting from fundamental requirements, such as the minimum speed and the ceiling, works that introduced the concept of conceptual design, comprehensive of the concept of feasibility study.

The semiempiric formula for the wing weight that was based on a rational analysis of the structure and on statistical analysis to determine coefficients and correction terms is shown in figure (4) in comparison with analogous formulas from other authors.

To the aforementioned concepts it is necessary to add his interest in the concept of the "weight growth factor" which can be found in the different meanings that appeared in international literature, to which he dedicated works and whose implications he explained to the scientists who were close to him. In short, in one of the meanings, such a factor is the ratio between the total weight and the weight known as fixed, of those parts, such as the paying load, the weight of the minimum crew and the weight of the fundamental instruments for the flight, which are not involved in changes when, at the level of the definition of the configuration, the performances and the characteristics of the machine are changed. In another meaning the weight growth factor is the derivative of the total weight with respects to the fixed weight, in the same vision of the change in performance and characteristics. In each case the value of the weight growth factor is expressive of the position of the operative theme with respects to the limits of feasibility: the higher the factor, the closer we are to the technological limits, where there is an infinite value. Two different definitions by Driggs and Ballhaus, respectively, are given in figure (5) together with the relative expressions in function of the relationships between the weight of the components and the total weight or derived from the same weights with respects to the total weight or to the wing surface. Obviously a lower value of the weight growth factor means a lower burden of the specifications with the same quality of design conditions and a better quality of design with the same specification conditions. An example of the concept of weight growth to analyse the burden of requests for variations of some specifications on the weight during the preliminary design is given in figure (6). For example, a request for greater strength would greatly influence the relationship between the structural weight and the total weight and with a variation of this relationship we would have the trend indicated by the weight growth factor according to Driggs.

Conceptual design, including feasibility studies**,** is now an essential step in the procedures of a design. **It has** different names in different languages and contents that are a little different from **one** language to another. Today **it** make up a significant part of a university discipline that we can call "system*s* engineering". At the Politecnico di Torino the spur in this direction, originating from Gabrielli, led to activities that have accompanied the evolution of the way of thinking in an international field. In order of time, studies were carried out on the evaluation of the weights of the various components of the aircraft*,* and on the identification of the repercussions of architectural choices at the "conceptual design" level. Later we arrive at the elaboration of automatic conceptual design methods, supplied with automatic graphic modules that are capable of visualising views and sections of the elaborated conceptual design, arriving in particular, for transport aircraft, at the modelling of an aircraft " capable of carrying out a mission" that can be automatically subjected to verifications for the various performances that are requested. More recently automatic methods have been developed relative to fighting and training aircraft, but also to transatmospheric vehicles with the introduction of modern parametric CAD instruments which allow architectural choices in the design and choices on the installation of the components of the onboard systems theory to be considered, with zonal verifications of the safety.

7) THE IMPORTANCE OF SAFETY AND RELIABILITY OF AN AIRCRAFT

Gabrielli's vision of safety was at the same time both professional and doctrinal. From the professional point of view, he gave a rigorous formulation to the industrial activity, separating the duties of calculation and testing, in this industry, both as far as static application loads and fatigue loads are concerned, which were then separated in the vision of the designer. The capability of performing static and fatigue tests, these being new in the Italian aeronautical field, was taken to levels of excellency, in the awareness that the last word on the correspondence of the structure to the requirements should in fact be given by the tests. He promoted, in particular, the setting up of test plants for fatigue testing both in the industrial and university environments and started experimental research of various kinds. For a long time, before important and significant capabilities were developed in other universities and industries, the Italian participation in the international debate on fatigue in aeronautics was basically given by the group of collaborators that he had started along this road. He in fact surrounded himself with clever collaborators who, while carrying out industrial duties in this field, were appreciated protagonists in the international debate, which was then completely open, on problems of structural safety in relation as to how to correctly carry out tests, on how to interpret and on how to derive data for the design and for the conclusions on safety. At the same time he promoted a capability of excellence in carrying out flight tests, thus covering all the problems of aeronautical design. From a doctrinal point of view, he understood that there was space for a theory on safety, in particular structural safety, as his publications on the subject demonstrate. This aspect, which we can define as the philosophy of design, and which faces the probabilistic aspects of safety in a modern way, with reference to all the aspects of the design itself, and with all the implications of a theoretical and conceptual nature, is cultivated at the Politecnico as a natural evolution of Gabrielli's ideas on the central theme of the conception of aerial machines.
He was surely amongst the first to realise the importance of reliability for the success of a modern aircraft. This affirmation does not derive from publications but rather from direct experience, no less important, relative to formulation stages of the design of an aircraft destined for an international competition, in which he imposed the adoption of parts, in particular those of plants, that were overdimensioned compared to the loads and deliveries, and with this choice, he explained to his collaborators, he intended to eliminate or reduce the probability of failures to a minimum. It is precisely because of this characteristic that the aircraft was able to win the competition, whose tests were carried out in Paris. Certainly the decisions that were adopted would seem drastic and rough today, but at that time more refined techniques did not exist to manage the problem and this type of " cutting the Gordian knot " appears not only as an intuition of the importance of reliability, but also as an anticipation of a position whose idea on the design has only recently come out, after a period in which the examination of the reliability was left to the last stages of the design, and that is, the insertion of the previsions of reliability and safety in the very first stages of the design, thus arriving at the design founded on risk analysis. In the same aircraft, the adoption of doors, bearing arms and ammunition, that were easy to substitute, shows us his anticipation of the advantages of easy maintenance and operative quickness. This aspect of Gabrielli's teaching, at the Politecnico di Torino, was developed through studies on onboard sub-systems and on safety, reliability, maintenance and costs and through the setting up of simulation models for aircraft and airforce operations. The course he was particularly fond of, "Aircraft Design", was developed with the main aim of presenting the design as optimisation in comparison with an operative theme, but under the condition of obtaining and demonstrating the degree of safety required by collectivity.

8) BEHAVIOUR OF THE COMPONENTS IN REAL RESTRAINT AND WORKING CONDITIONS

He was surely amongst the first, in agreement with his collaborators, brought up at the school of design problems, to express the necessity of examining the behaviour of each single component, the equipment or the structures, under actual working conditions. As far as the equipment is concerned, the idea led to, for example: the determination of the actual value of the elastic modules of the cables used in the mechanical flight control circuits with specific tests in order to better calculate their behaviour. An analysis of the elastic modulus (conventional for reference areas) of a typical mechanical flight control circuit cable is reported in figure (7): the cable is a very complex structure and both the results of simplified theories and the experimental results are shown in the figure and these show that the elastic modulus can be considered constant in a band of values of the applied stress. Considering the real working conditions of each component also leads to dynamically determining, with conditions created by the artificial sensitivity pre-loads, by the laws on the opening of the specific tests, the behaviour of the flight control systems, taking into consideration the actual distribution flaps of the hydraulic jacks and of the deformation of the mechanical circuit, including the hydraulic oil, therefore in a non linear and most realistic vision of the problem, which is fundamental in the study of the causes of the greatest and least approval of the handling qualities of aircraft by the pilots. It is from these studies that sophisticated analysis of the behaviour of the flight control systems have stemmed, in which mechanical play is taken into consideration, this being another source of non linearity together with friction. As known, the part played by the behaviour of the control line was studied in particular in the decades immediately after the second World War: Gabrielli was one of the scientists who sensed the influence of friction and of play in the circuit on control, and also the stabilising effect of the stick force components which are antagonists of the control speed and are therefore basically damping. Among the numerous ideas he advanced and examined there was that of reducing the frictions in the mechanical flight control circuit through the use of mechanical vibrations imposed on the circuit: some experimental results obtained on a flight control circuit by Gabrielli in collaboration with Cereti and myself are reported in figure (8). On this subject , Cereti and I , in the attempt to supply a basic theory for Gabriell's idea, also faced the non linear problem of apparent friction in a cinematic couple subject to friction, but otherwise constant. The graphics of the apparent friction in function of the parameters that characterise the vibrating force with which it imposes movement to the cinematic couple are shown in figure (9). If we distinguish, schematically speaking, between friction and play in the reversible control line and in the portions above the servocontrol in the hydromechanical irreversible circuits (mainly adopted in Gabrielli's time) and friction and play in the servocontrols and in the portion of line below in the irreversible lines (occurring later), they directly influence the stick forces in the first case, while, in the second, they have an effect on the dynamic behaviour of the servocontrol. In both cases they however influence the dynamic quality of the pilot-control-aircraft-stability augmentation system. In the years in which Gabrielli dedicated himself to these studies, the flight controls offered the first example*s* of friction and play in the control of the aircraft, and it is therefore natural that he dealt with this problem, realising the importance of friction and play on the control of the aircraft, and he reached the conclusion that it was better that they were limited both to a lower degree (truncation of the environmental perturbations) and to a higher degree (precision of the control actions). Gabrielli's intuition still today remains valid, even with the passage to irreversible controls, an intuition that can today be formulated by saying that in particular the friction acting on the actuator set of the mobile surface should not be too large to ensure the accuracy of the regulation function, but should not be too small in order to perform a contrast action against the small, accidental perturbations.

As far as the structures are concerned, it is particularly important the idea of examining the structural behaviour, in real working conditions, of each single component, constrained by its belonging to the structure to deformations which, together with the applied loads, can cause evolutions that are non linear, of the state of the component itself. This line of thought led to experimental works on bending and on torsion of box structures, that have shown the importance of the effects of concomitance between the deformations induced by the fact that they belong to the structure and the applied loads and in some cases also the effects of the aforementioned deformations on the appearance of bending phenomena. The results relative to a particular example of a wing section subject to pure bending, that is part of a wider experimental research, is shown in figure (10). The test, and to a certain extent, the test equipment, are illustrated in the same figure. The trend of the displacements in function of the parameter proportional to the applied moment clearly indicates the form of the deformation and the presence of a transversal pressure effect due to the basically cylindrical shape assumed by the panel due to the effect of belonging to the box. It was possible to discover an effect that was unknown in literature for which rectangular panels of a box structure, subject to torsion, can behave like triangles, because of the rotation of the transversal sections, according to the triangles generated by their diagonal, which, because of the distorsion induced in the panel, behaves like a stiffening effect. This effect has been explained theoretically, taking into account the induced deformations. The behaviour of sufficiently large panels, in relation to the thickness, can be seen in figure (11) so as to be able to show the aforementioned effect and also the trend of the torsional stiffness in the closeness of the buckling moment.

9) FEASIBILITY AND OPTIMISATION OF THE STOL AND VTOL AIRCRAFT

The contribution made by Gabrielli to the international discussion on feasibility and on optimisation of the STOL and VTO aircraft was probably the most pregnant relative to the design, in particular concerning the conceptual design and the preliminary discussion on the burdens, above all as far as weight is concerned, of the various requirements. The fundamental ideas of the studies of conceptual design that are also presently carried out can be found, explicitly or "in nuce" in a parametric study that was presented at an international meeting dedicated to the subject. For the preparation of this study, which was presented as the official study of the most important Italian company engaged in an international competition that did not have a practical sequence, he called on technicians reared at his school of design to collaborate on the project, giving precise and rigorous indications, from the engineering point of view, on the aim, on the modalities and on the sources to use, and obtained an organic and innovative work as far as the formulation of the work is concerned. The conclusions of this study concerning two architectural solutions are given in figure (12), one concerning a single engine capable of a vectored thrust and one with a propulsion engine system and compound lift, for which, at a conceptual design level, there is a net prevalence for the second. The net prevalence for the same compound solution is shown in figure (13) as far as flexibility of the design is concerned, due to the influence of the radius of action on the total weight. The flexibility of the design for both solutions is shown in figure (14) due to the influence of the radius of action on the paying load, the other conditions being the same. Finally, the influence of the military load on the total weight, with the other conditions being the same, is shown in figure (15).

10) SPATIAL ACTIVITY AS A LOGICAL EXTENSION OF AERONAUTICAL ACTIVITY

Spatial activity appears as a logical extension of aeronautical activity, above all in the preparation of systems that are able to carry out the activity itself. When the time was right for our country to enter into this sector, Gabrielli imparted the impulse to extend the aeronautical industrial field to space, beginning with the design and production of artificial satellites and thermal shields to protect them during the first stages of launching. There also followed, in this field, the idea of using true research activities side by side with the industrial activities both in industry and in the university, promoting research on advanced materials, such as ablative materials, boron fibres and so on. The designing of thermal shields led, in particular, to master the technology of composite materials, in which the industry in our country found important work opportunities. Later the industrial activity was extended to interests of various types. The Politecnico di Torino dedicated a great deal of energy to composite materials with extensive experimental investigations and detailed theoretical analysis that have led it to be in a position of excellence in the international field. The experimental aspect was started by Gabrielli with research concerning basic aspects of a general nature: the behaviour of temperatures different from the natural environment, the influence of deviations of polymerisation cycles from the correct ones on the mechanical characteristics, the behaviour at fatigue and others. At a later point, research was carried out *by Gabrielli* on thermal expansion and hygroscopic coefficients in the typical conditions, temperatures and pressures of spatial use, activities that required the preparation of adequate experimental apparatus, on the technology of the production of structures in composite materials, on the postcritical behaviour of smooth and ribbed panels, subjected to combined loads, this activity being a continuation of Gabrielli's analogous research into aluminium alloy panels and finally research into the behaviour of wing box subject to bending or torsion, in line with the aforementioned investigations taking into consideration the effect of belonging to complex structures for the deformations imposed on the individual elements. The composite materials and the structures in these materials became a point of excellency of the theoretical research at the Politecnico di Torino where at present several scientists who are well known at an international level work.

CONCLUSIONS

It is possible to state that the personality of Gabrielli allowed him to leave a mark on all aspects of aeronautical and spatial activities, in particular those of our country.
It therefore seems to me appropriate to close this intervention by recalling him with a proposal concerning the problem of safety in space. At present space systems, especially those that are manned, are promoted and made by government agencies or agencies that are similar to government agencies, and which therefore can consider the expressions of collectivity. These agencies also indicate and decide the levels of safety that are acceptable. On the other hand, the crews that have so far been involved should be considered highly specialised and aware of the nature of the missions entrusted to them. If we are going to involve people who are less aware and dedicated, eventually including simple passengers, it would seem auspicable that the two functions of creating a system and deciding the admissible levels of safety should be entrusted to different organisations in such a way that the one whose duty is to define safety is also entrusted with the job of verification. Such an organisation, an expression of the collectivity in the ways that each country wishes to adopt, should proceed with the homologation of each design and the registration of each vehicle, which should be accompanied by prescriptions on the modality of use, things that all bear witness to the satisfaction of the established safety levels. In this way the organisation that creates the system could even be *private.*

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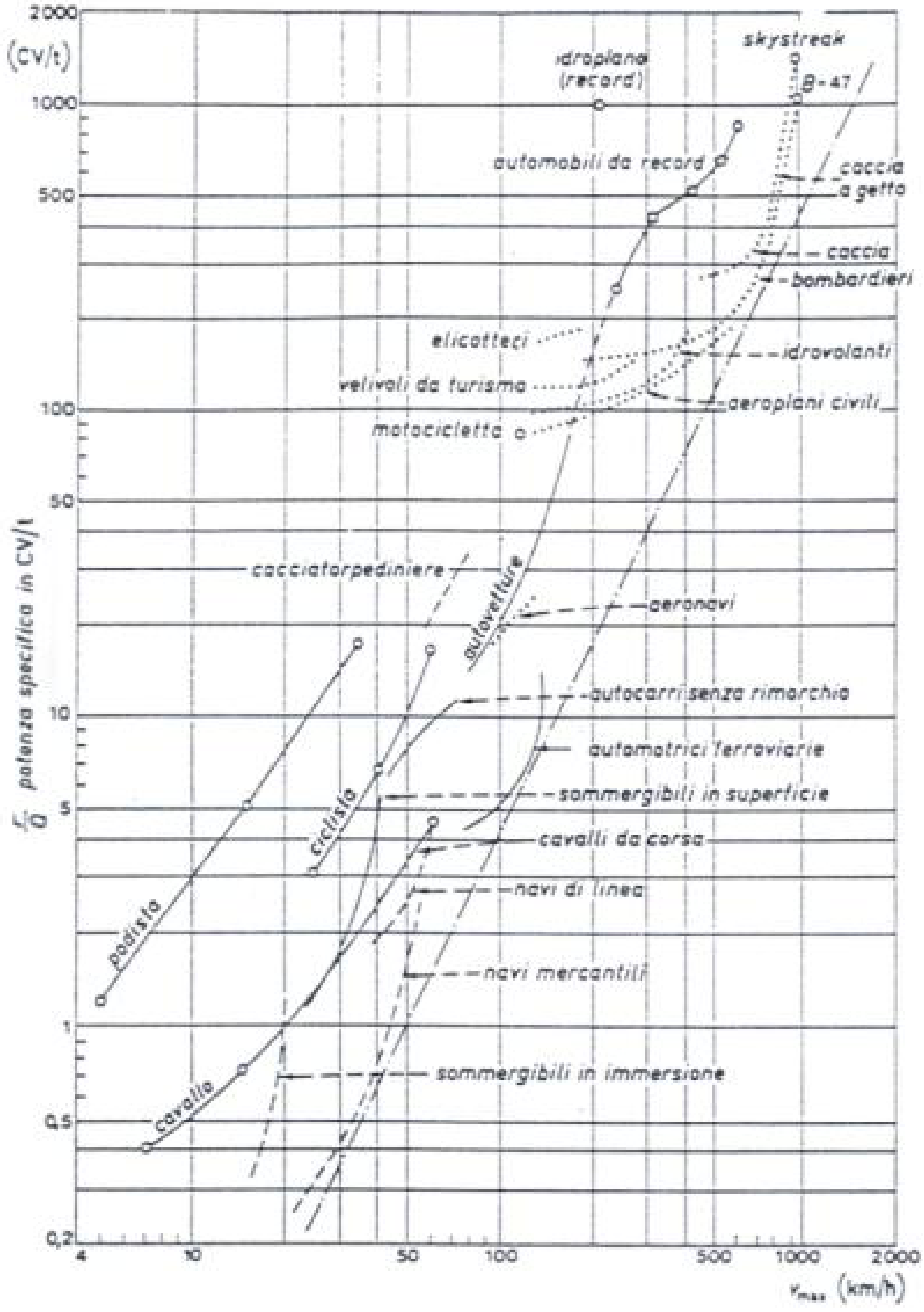
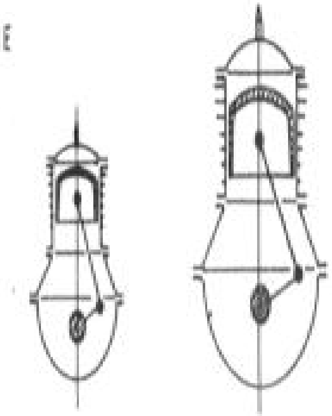
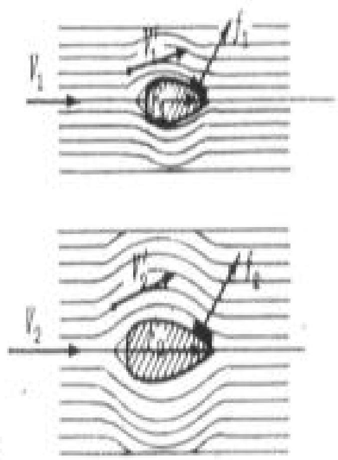


Fig. 1. Specific power for single vehicles [3].





LEGGI DI SIMILITUDINE

SIMILITUDINE GEOMETRICA
- Lunghezze : $\lambda = \dfrac{l_1}{l_2}$
- Superfici : $\lambda^2 = \dfrac{A_1}{A_2}$
- Volumi : $\lambda^3 = \dfrac{V_1}{V_2}$

SIMILITUDINE CINEMATICA
- Tempi : $\tau = \dfrac{t_1}{t_2}$
- Velocità : $\lambda\tau^{-1} = \dfrac{V_1}{V_2}$
- Accelerazioni : $\lambda\tau^{-2} = \dfrac{a_1}{a_2}$

SIMILITUDINE MATERIALE
- Masse : $\mu = \dfrac{m_1}{m_2}$

SIMILITUDINE DINAMICA
- Forze : $\varphi = \dfrac{m_1 a_1}{m_2 a_2} = \mu\lambda\tau^{-2}$

CASO DELLA CORRENTE FLUIDA PERMANENTE

$$\frac{f_1}{f_2} = \mu\lambda\tau^{-2} = \frac{\rho_1 l_1^3}{\rho_2 l_2^3}\frac{l_1}{l_2}\frac{t_2^2}{t_1^2} = \frac{\rho_1}{\rho_2}\frac{l_1^2}{l_2^2}\frac{l_1^2}{t_1^2}\frac{t_2^2}{l_2^2} = \frac{\rho_1}{\rho_2}\frac{l_1^2}{l_2^2}\frac{V_1^2}{V_2^2} = \frac{\rho_1 A_1 V_1^2}{\rho_2 A_2 V_2^2} = \text{costante}; \quad \text{ossia} \quad \frac{f_1}{\rho_1 A_1 V_1^2} = \frac{f_2}{\rho_2 A_2 V_2^2} = \text{costante}$$

Per la forza complessiva sul corpo (resistenza) si ha:

$$\frac{P_1}{\rho_1 A_1 V_1^2} = \frac{P_2}{\rho_2 A_2 V_2^2} = \text{costante} = \frac{P}{\rho A V^2}$$ COEFFICIENTE DI RESISTENZA DI NEWTON

Fig. 2. Similarity laws examples [3].

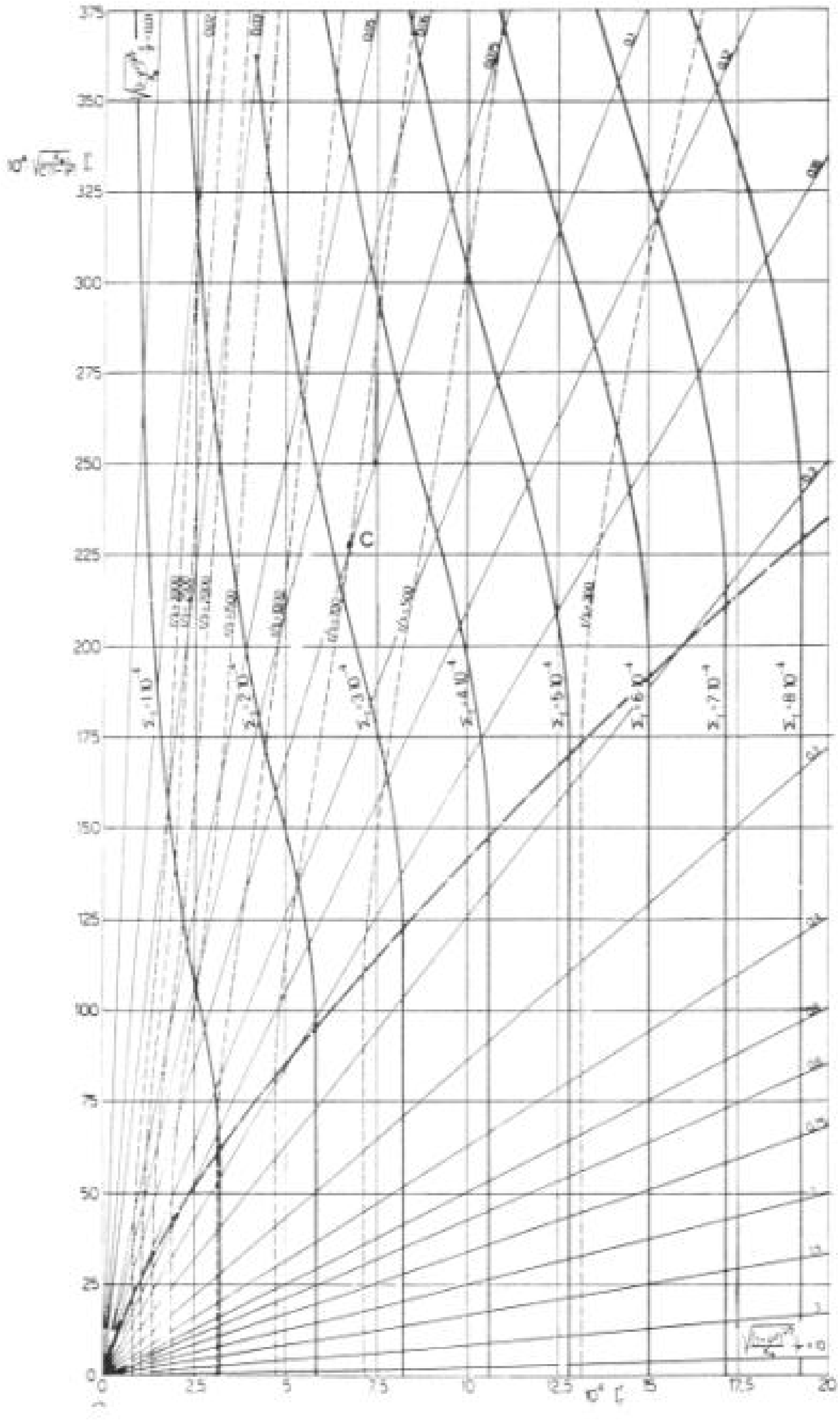


Fig. 3. Local buckling for long and transition cylinders [11].

Formula di *G. Gabrielli*(*)	
Peso della struttura alare (kg_p)	$k = 1,94$
	$\lambda = b^2/S$, rapporto di allungamento
	N, fattore di carico a robustezza
$$Q_{sa} = k\lambda NQb\,\frac{\gamma}{\bar{\sigma}_r^*} + 6S$$	Q, peso di progetto del velivolo (kg_p)
	b, apertura alare (m)
	γ, peso specifico del materiale (kg_p/m^3)
	S, superficie alare (m^2)
	$\bar{\sigma}_r^*$, tensione di rottura e strappamento (kg_p/m^2)

Formula di *I. H. Driggs*(*)	
Peso della struttura alare (kg_p)	$\alpha = 1 - (s_e/l_e)/(s_i/l_i)$(**)
	$\beta = 1 - (l_e/l_i)$(**)
	s_i, spessore del profilo di incastro (m)
$$Q_{sa} = 0,665\left[4,95 + \frac{b}{s_i}\,\frac{1}{\cos\Delta}\,\varphi(\alpha,\beta)\,NQb\,\frac{\gamma}{\sigma_p}\right]$$	s_e, spessore del profilo di estremità (m)
	l_i, corda del profilo di incastro (m)
	l_e, corda del profilo di estremità (m)
	Δ, angolo di freccia
	σ_p(**), tensione media di sfruttamento del materiale ($kg_p\ m^{-3}$)

(*) In [3].

(**) $\varphi(x,\beta)$ and σ_p are obtained from diagrams.

Fig. 4. Examples of semi-empirical laws for the calculation of weight for wing structures.

Total weight subdivision

$$Q = \mathbf{F} + Q_s + Q_p + Q_b$$

with:

$$\begin{aligned}&F = \text{fixed weight, not depending from lay-up and performances}\\ &\text{variable weight}\begin{cases} Q_s = \text{structures weight}\\ Q_p = \text{propulsive system weight}\\ Q_b = \text{fuel weight}\end{cases}\end{aligned}$$

a) growth factor following Driggs $\qquad G = \dfrac{Q}{F}$

$$G = \frac{1}{1 - \left(\dfrac{Q_s}{Q} + \dfrac{Q_p}{Q} + \dfrac{Q_b}{Q}\right)}$$

b) growth factor following Ballhaus $\qquad G = \dfrac{dQ}{dF}$

$$G = \frac{1}{1 - \left(\dfrac{Q_p}{Q} + \dfrac{Q_b}{Q} + \dfrac{S}{Q}\dfrac{\partial Q_s}{\partial S} + \dfrac{\partial Q_s}{\partial Q}\right)}$$

where:

$$Q_s = Q_s(S, Q) \quad , \text{S=wing surface}$$

$$Q_p = Q_p(Q), \quad \frac{\partial Q_p}{\partial Q} = \frac{Q_p}{Q}$$

$$Q_b = Q_b(Q), \quad \frac{\partial Q_b}{\partial Q} = \frac{Q_b}{Q}$$

Fig. 5. Growth factors [10].

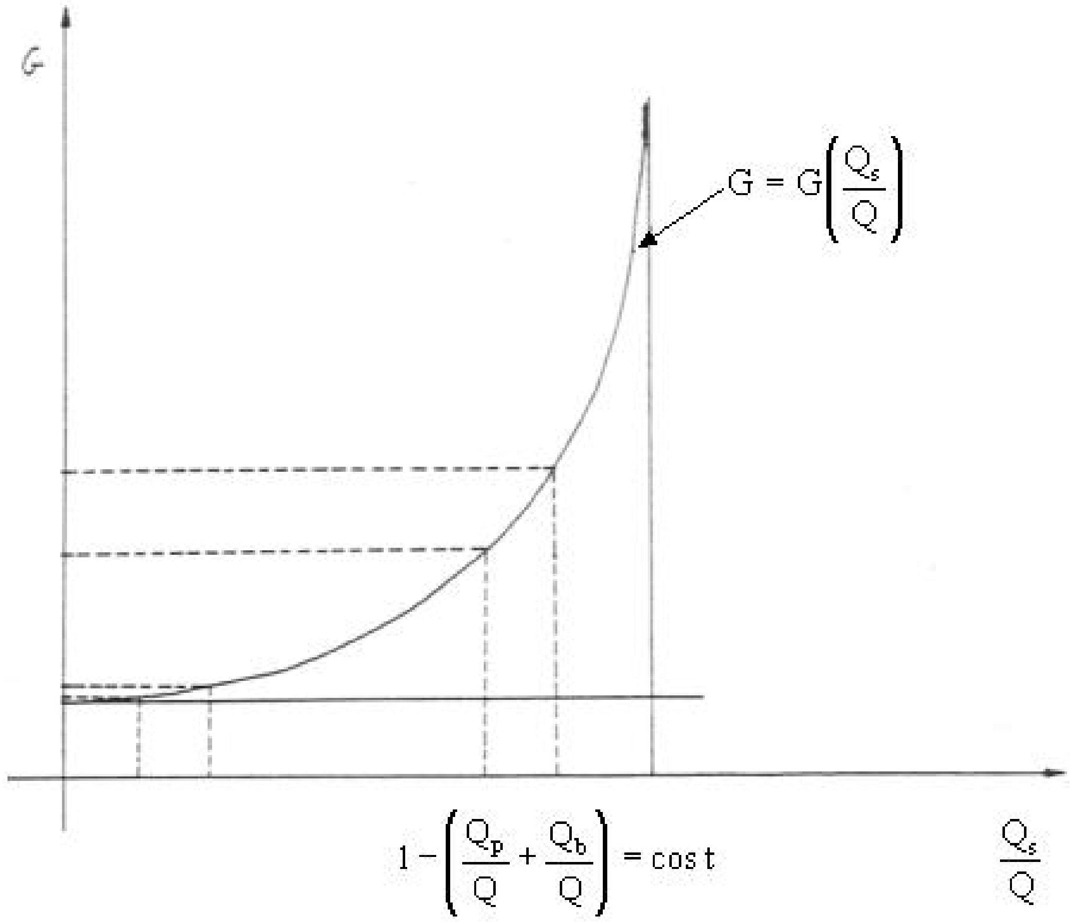


Fig. 6. Effect of robustness (n) on the growth factor following Driggs, $Q_s = Q_s(n)$.

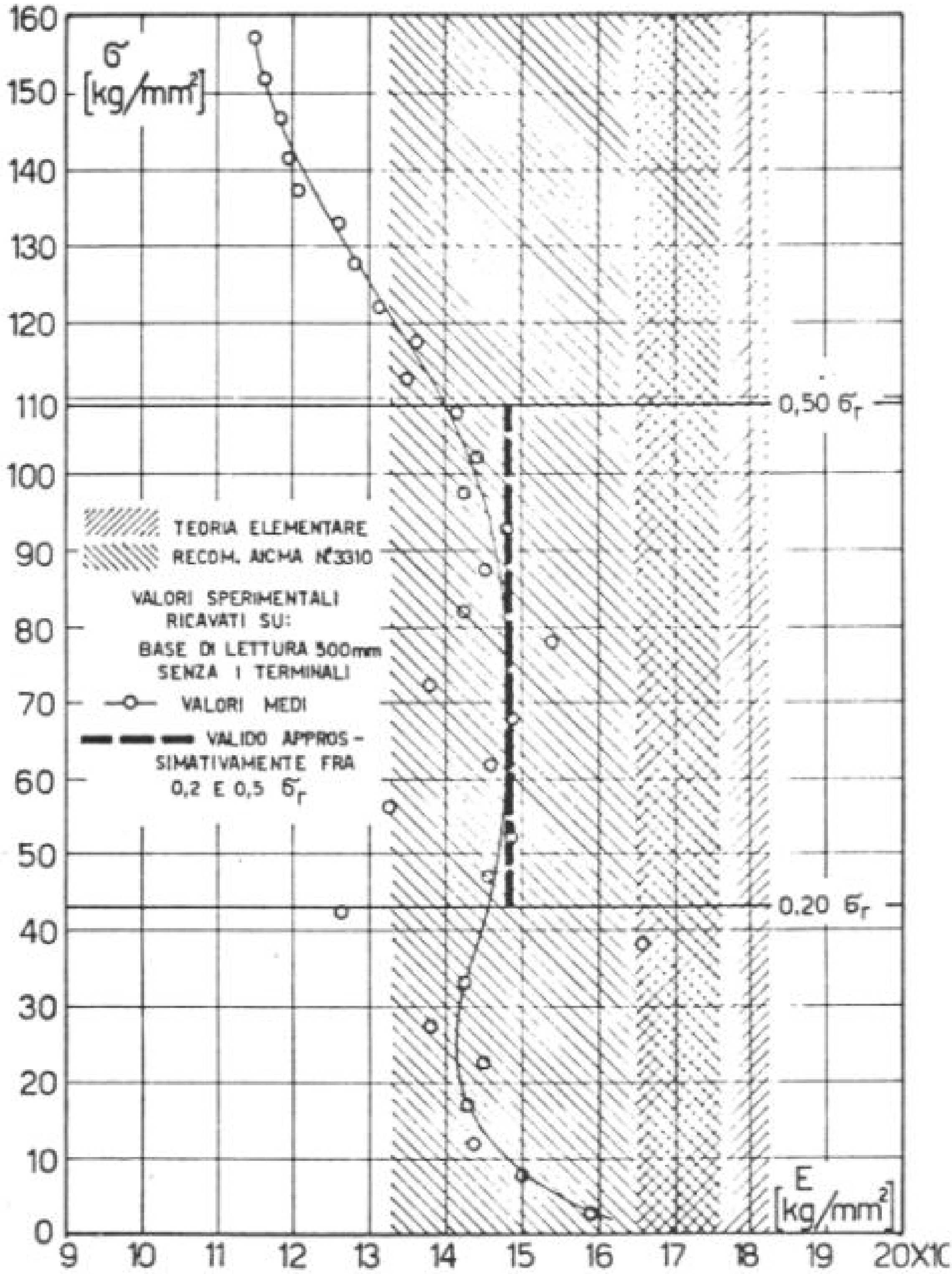


Fig. 7. Preformed cable, D = 18''. Elastic modulus as a function of stress σ [7],[8].

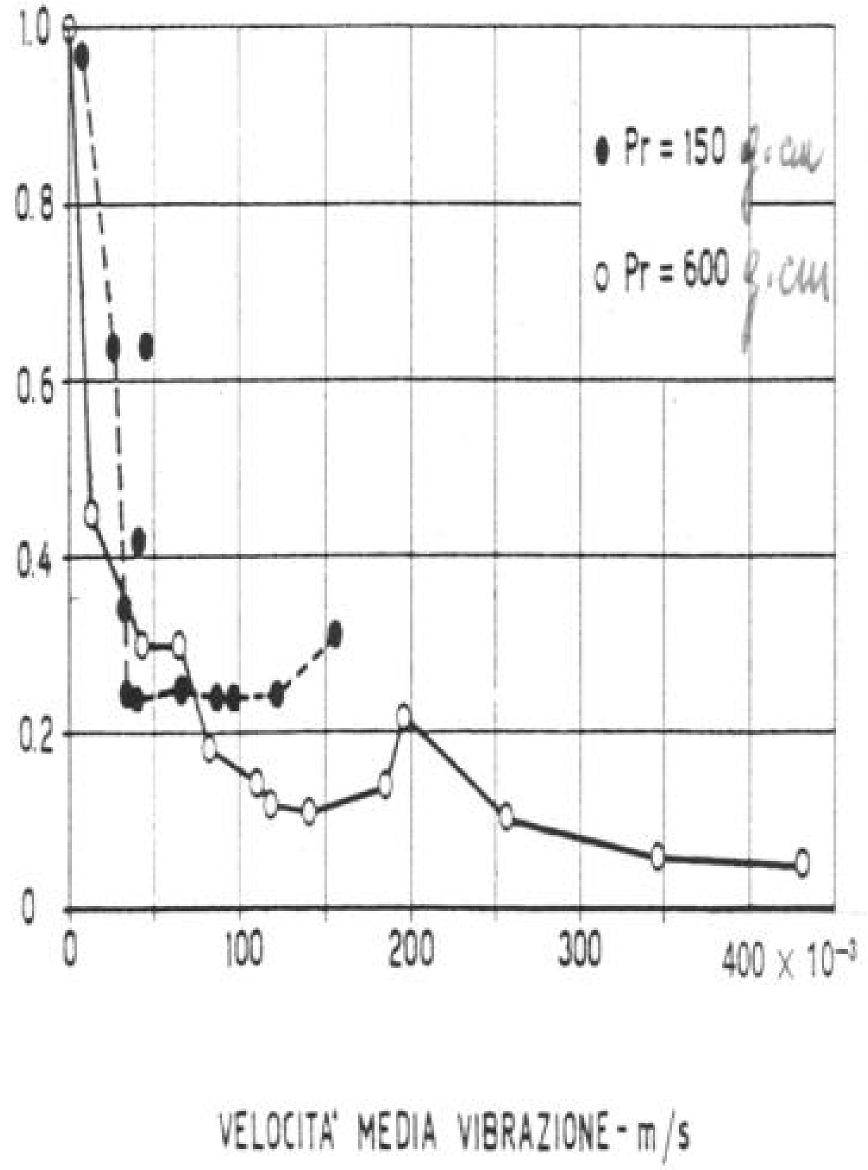
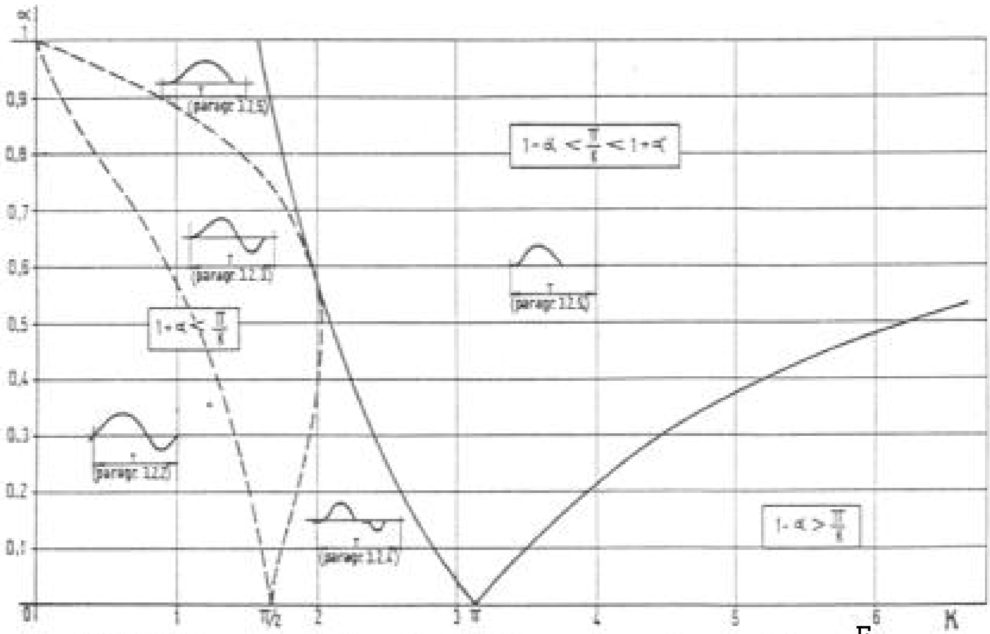
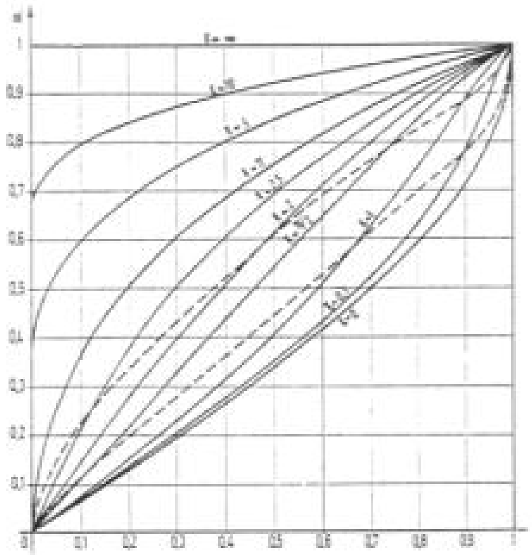


Fig. 8. Effect of an eccentric mass vibrator, aleirons transmission chain for G 82 [6].



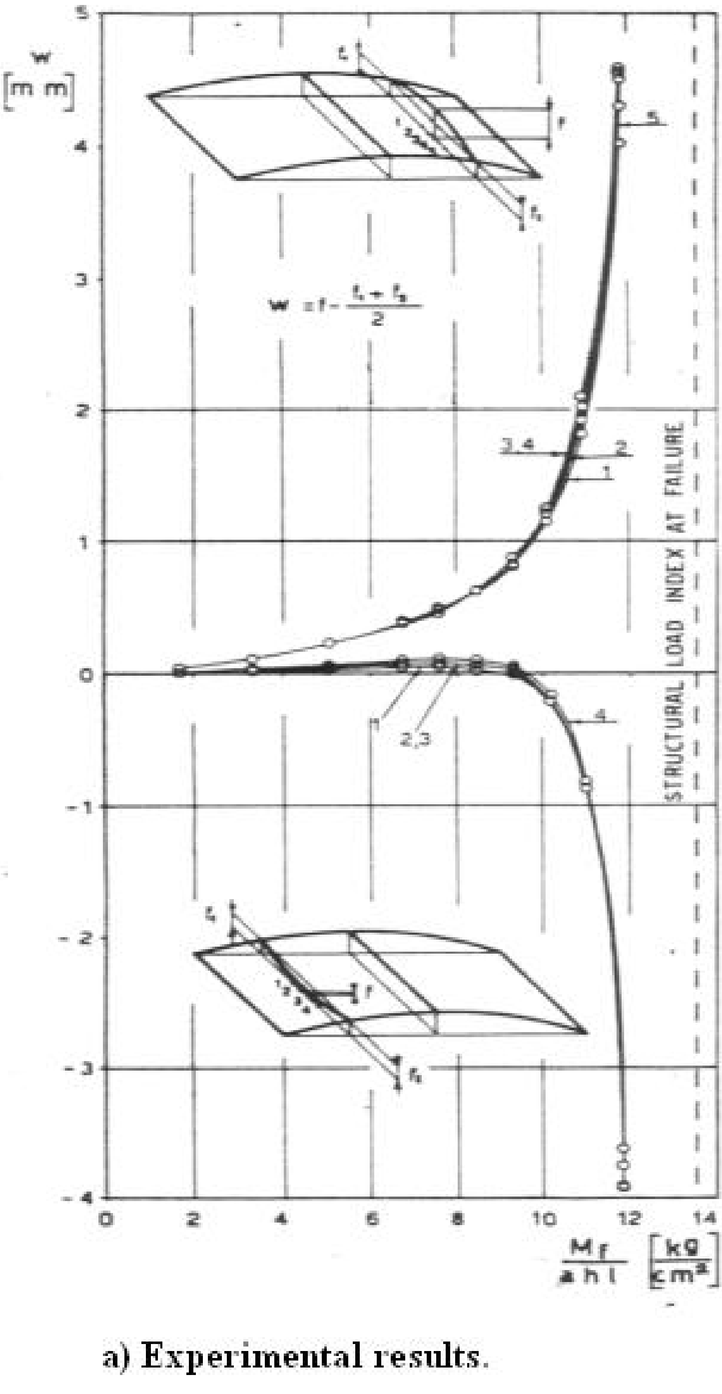
a) Validity range for the different motions: $K = \pi \frac{F_0}{F}$



b) Apparent friction α as a function of $H = \frac{V_m \omega}{F}$ for different K:

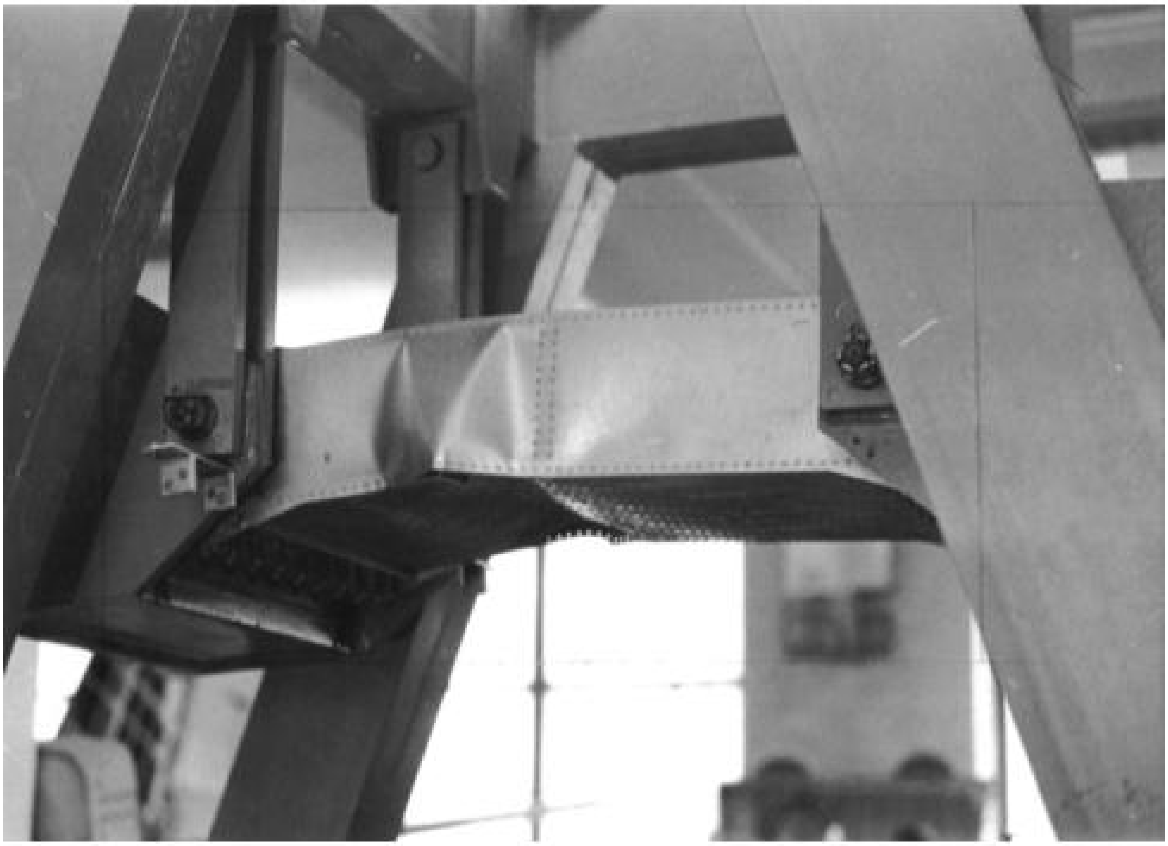
V_m = average speed; ω = exciting force frequency.

Fig. 9. Apparent friction in a cinematic couple with constant friction F_0 , moved by F_1 , effect of a vibrating force with intensity F [5].



a) Experimental results.

Fig. 10. Wing box bending: effects on the panels due to the applied loads and to the box itself [12].

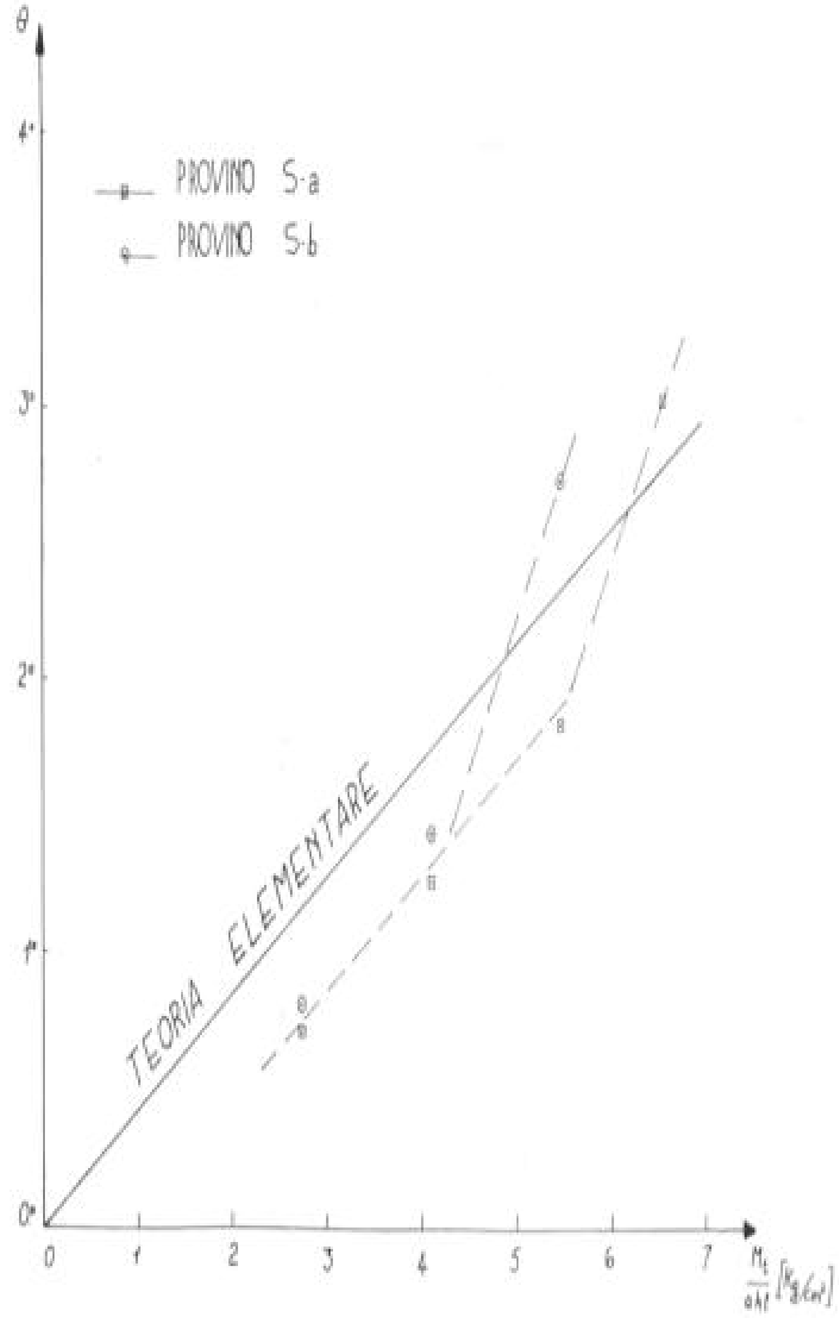


b) Experimental set-up.

Fig. 10. Wing box bending: effects on the panels due to the applied loads and to the box itself [12].

a). Torsion tests on wing boxes [13],[14].

Fig. 11



b) Rotations of terminal sections.

Fig. 11

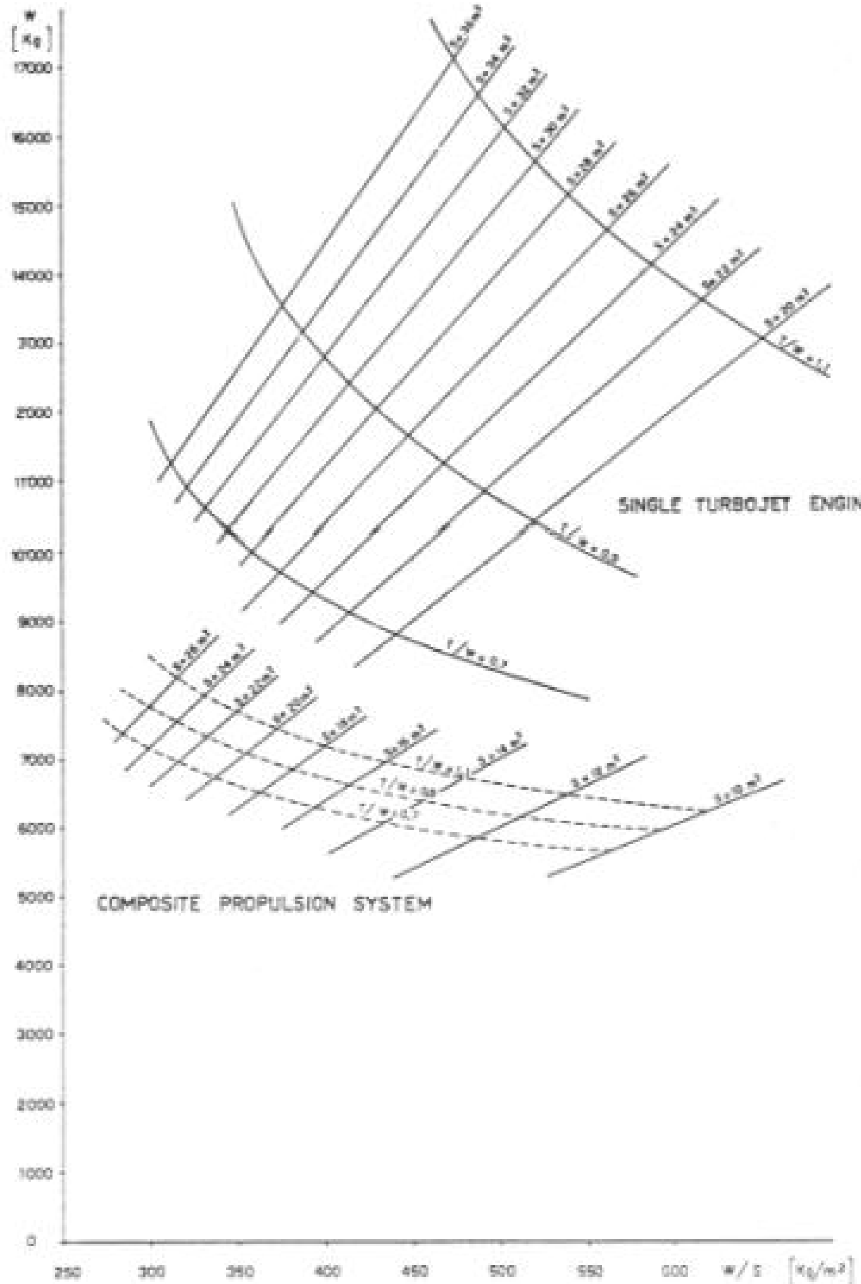


Fig. 12. Feasibility and optimisation for STOL and VTOL vehicles.

Total weight of a vehicle for fixed requirements: parametric study depending on W/S and T/W, for two cases of propulsive system [16].

W = total weight; S = wing surface; T = maximum thrust.

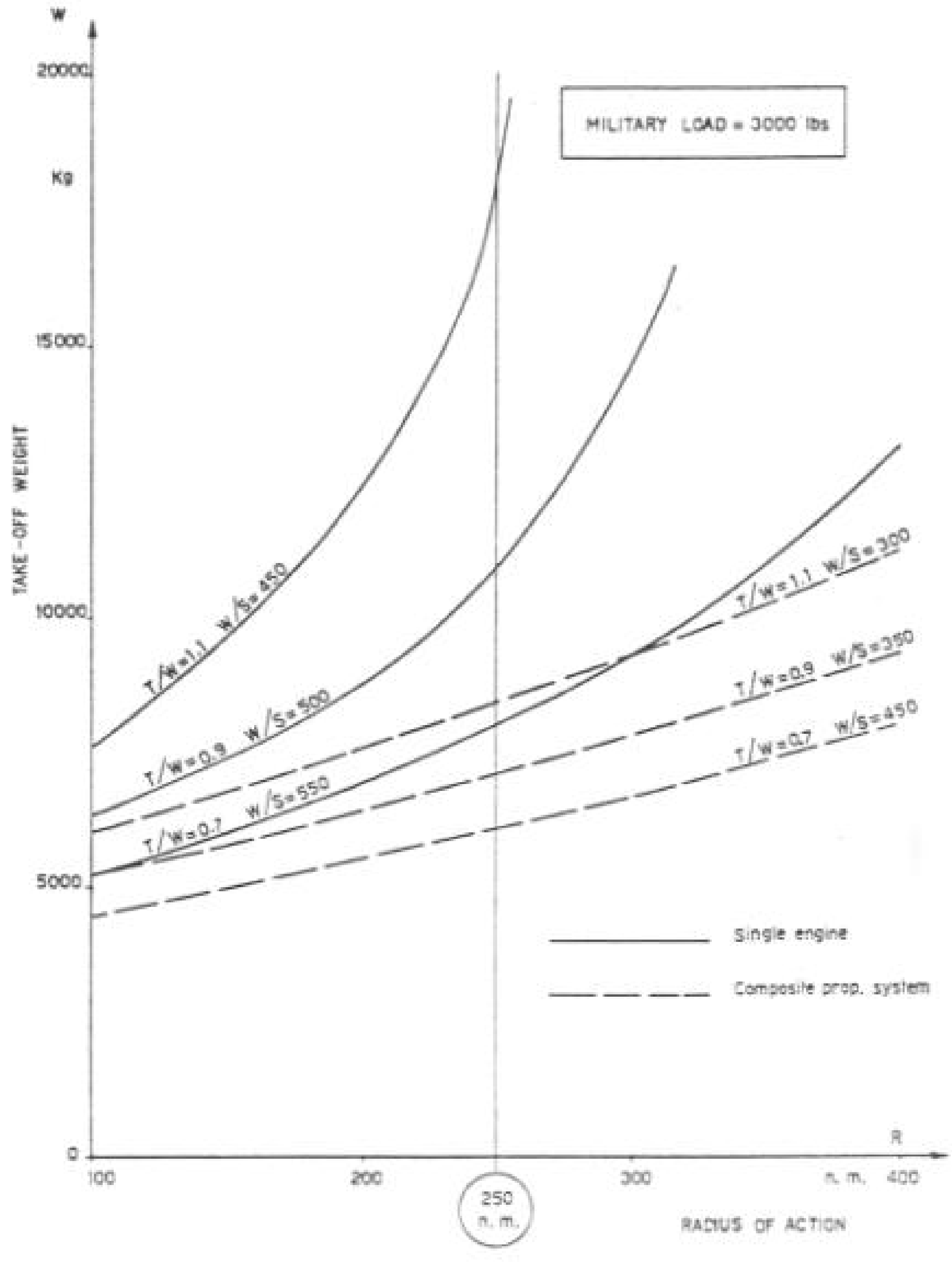


Fig. 13. Design flexibility: total weight as a function of the radius of action (see also Fig. 12) [16].

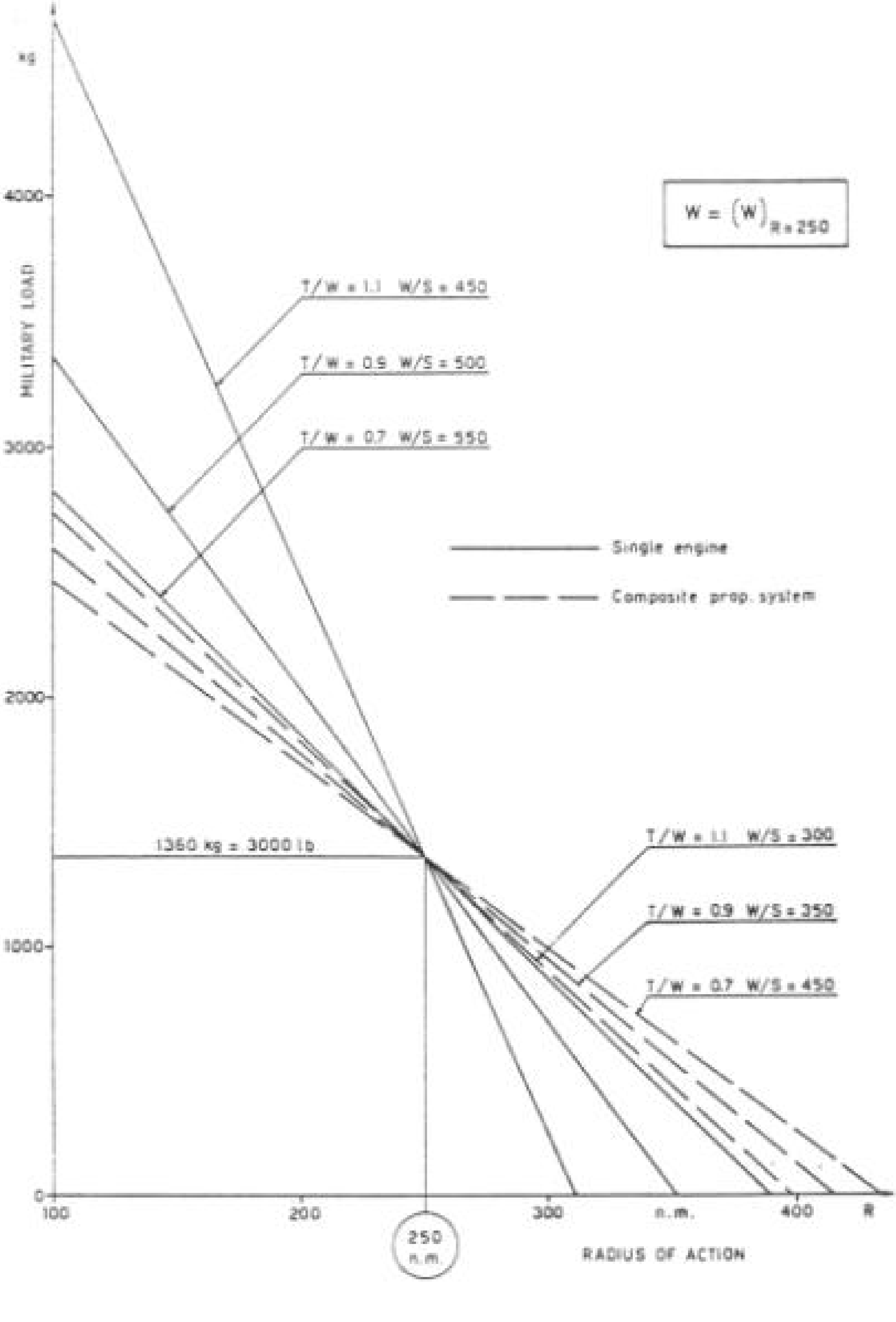


Fig. 14. Design flexibility: military load as a function of the radius of action (see also Fig. 12) [16].

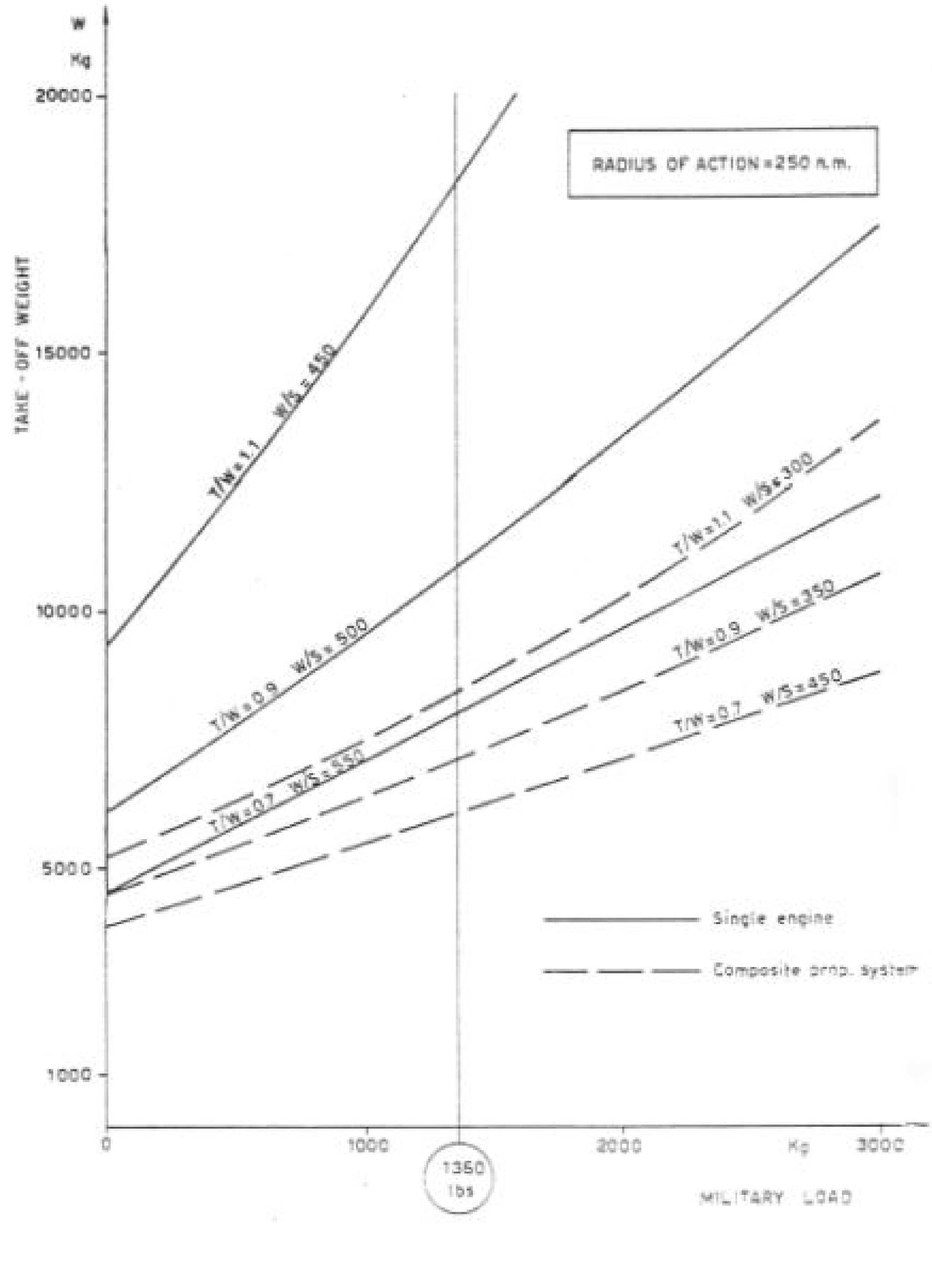


Fig. 15. Design flexibility: take-off weight as a function of the military load (see also Fig. 12) [16].