CLASSIFICATION IN FLIGHT MECHANICS

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Abstracts

After the signification and problematics of the classification in mechanics of flight having been explained a short survey of the historical development of flight mechanics is given. Further the questions of a classification method based on the predicate analysis are discussed. A classification in flight mechanics is then proposed in two stages. The first stage comprises the basic classification of flight mechanics as of a science. The topic of the second stage is the classification of phenomena which are dealt with in flight dynamics as in a part of flight mechanics. The classification is supplemented by definitions of the contained concepts and terms.

1. Introduction

The existing evolution of sciences, especially of the natural and technical ones, has acknowledged that one of the preconditions of their systematic and effective development is a classification of the searched objects and phenomena in the given discipline into a specified and clear system. For the purpose of it a classification method may be used by which this classification is done according to certain attributes of congeniality and according to specified rules into a system of classes and groups. With a classification also a precise statement of the sense of various terms is connected which are comprised in the respective classification system and to which also unique equivalents in different languages should be joined to facilitate the international cooperation in the given discipline.

Flight mechanics deals with study of motions of aircraft and of their parts in connection with causes of these motions. The classification system discussed in this paper is limited just to mechanics of atmospheric flight. This is an applied scientifical discipline which utilizes knowledge not only from mechanics of rigid and deformable bodies and from aerodynamics, but also from theories of propulsion, from theories of control, cybernetics, biomechanics, applied and numerical mathematics and system theories, see fig.1. Flight mechanics keep evolving unceasingly in accordance with development of scientific disciplines, the results of which it applies, and also according to the progress in the engineering of aircraft, the motion of which it studies. Therefore the classification and terminology in flight mechanics should be in relation to those sciences which it applies. Flight mechanics has a very broad use beginning with the aeronautical research and finishing with pilots training, see fig. 1. In the classification thus also the view-points of spheres should be taken into account which are using acquaintances from flight mechanics. Especially some convenient criteria should be emphasized for to judge quantitatively the classified phenomena.

Already from the beginning of flight mechanics approximately in 1920 attempts were made to classify this discipline what can be seen from the enclosed list of picked out referencies, enclosing books, monographies, requirements, standards and vocabularies. The progress in disciplines applied in flight mechanics and the progress in the development of aircraft have got so far that it seems to be beneficial if the existing classification in flight mechanics would be evaluated, supplemented or even changed which should be done on an international basis. The usefulness of it is confirmed by the fact that on the 23rd meeting of the Subcommittee ISO/TC 20/SC 3 "Terms and symbols in flight dynamics" held in 1978 in Paris, the Czechoslovak member body was put in charge of preparing a proposal of a classification of basic terms in flight mechanics which after discussions and aproval should get a new part of the International standard ISO 1151 "Terms and symbols in flight dynamics". To this aim a new proposal of basic classification (46) was elaborated in 1979 based on studies in ref (9 and 45).

In the presented paper, in contradiction to ref.(45 and 46), in the classification method the predicate analysis is used which makes possible to describe phenomena qualitatively. The enclosed proposal is just one of possible solutions and deals with a more detailed classification than is the basic one in (46).

2. Short historical survey

In its first beginnings in 20th, flight mechanics was set into order of applied aerodynamics, see e.g. Bairstow (1). But in a good time, it was considered as a selfreliant discipline which in the English literature was usually called "Dynamics of flight", see e.g ref. (5, 18, 22, 31), with exception ref. (24), where the term "Flight mechanics" was used. In other languages the following terms are usual: in French "Mécanique du vol", see ref. (39, 66), in German "Flugmechanik", see ref. (35), in Russian "Mechanika poleta" in (40) or "Dinamika poleta" in ref. (14, 25, 27, 38, 43 and 46), and in Czech "Mechanika letu", see ref. (13, 48).

Already in the oldest references one can find the flight mechanics to be divided into "aircraft performance" and "flying qualities", see e.g. ref. (3, 10, 12). In the book (45) by Etkin, the flight mechanics comprises also "aeroelasticity" which at that time usually untill now is considered to be a selfreliant applied discipline on the boundaries between flight mechanics and aircraft stress analysis, see e.g. (16, 23). Aeroelasticity comprises elastic motions of deformable parts of aircraft as are wing, tailplanes and fuselage. These motions can affect motion of the whole aircraft and on the contrary the aircraft motion can affect elastic motions of the aircraft parts. Therefore in recent years a tendency is evident to consider the effect of aircraft structure distorsions on flying qualities, see ref. (21, 29), and especially to solve flying qualities and aeroelastic qualities of an aircraft

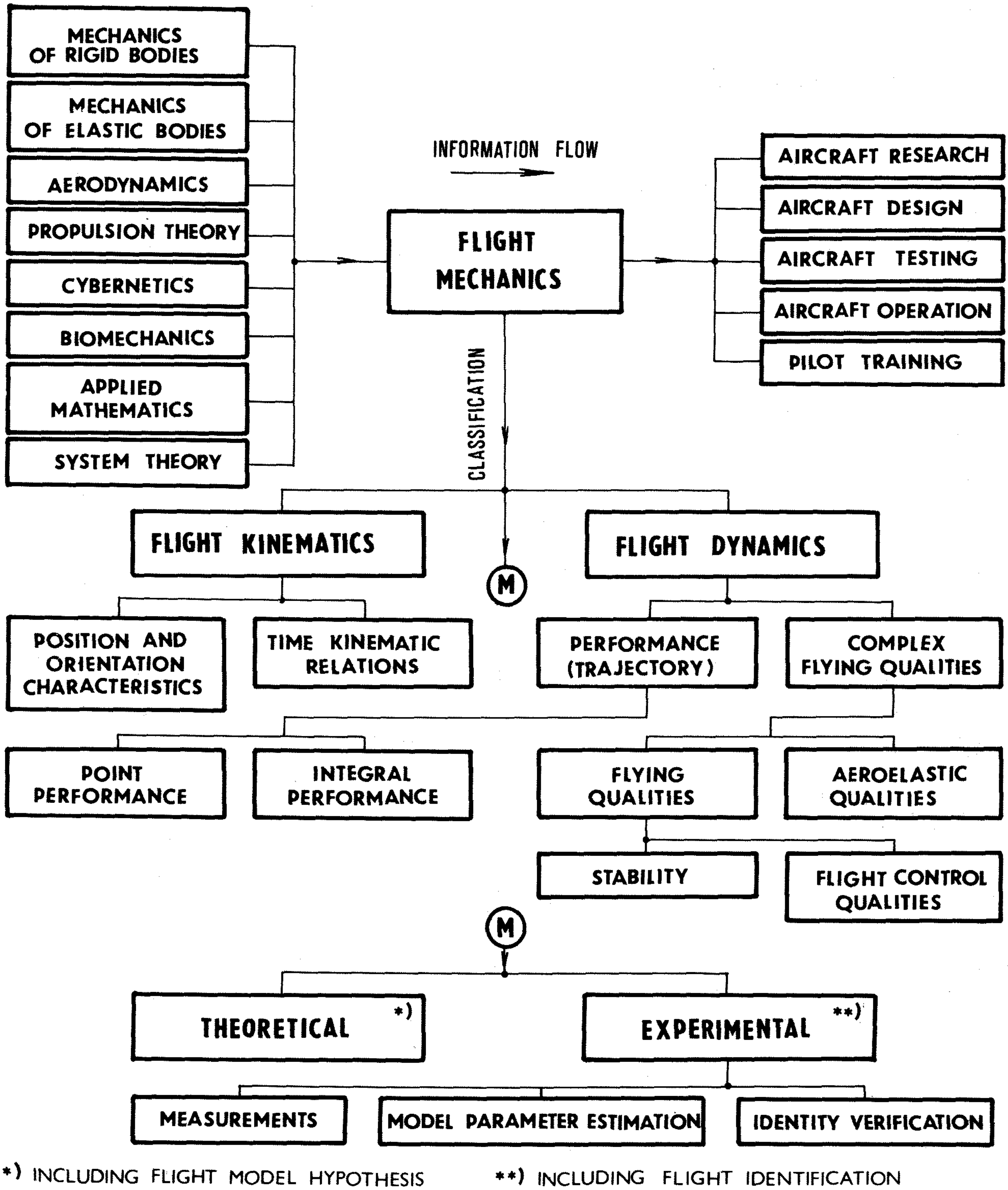


FIGURE 1 - SCHEME DIAGRAM OF DISCIPLINES APPLIED IN FLIGHT MECHANICS, ITS UTILIZATION AND BASIC CLASSIFICATION

simultaneously by using a complet mathematical model, see e.g. ref. (47).

In flight mechanics text books also chapters are usually enclosed which deal with necessary aerodynamic data and also with coordinate axis systems, with orientation angles of these systems, with transformation matrices of vectors components and with various kinematic relations, see e.g. ref. (22, 31, 47). In accordance with classification in classical mechanics, in such last mentioned chapters "kinematics of flight" is in fact dealt with which term however is not usual. The rest of chapters in the books are then dedicated to the proper "dynamics of flight" which comprises problems of aircraft forces equilibrium at steady and unsteady flights, see e.g. (6).

In bibliography one can find also books dealing with "experimental flight mechanics", see e.g. ref. (3, 11, 44). They usually comprise chapters about instruments and methods used at flight measurements of kinematic and dynamic quantities and about special methods for evaluation of recorded values of the measured quantities. From the beginning a lot of attention was paid to corrections of systematic errors caused by nonstandard conditions of flight measurements. These corrections were usually called "reductions to standard conditions", see e.g. (11). In the recent 20 years a lot of works was published about parameters estimation of mathematical models for various motions of an aircraft by using flight measurements data, see e.g. (44,50). These works have created a basis for identification studies in flight mechanics, see e.g. (52), which are of gnoseological nature, because they investigate the identity of chosen attributes stated in flight on an aircraft and of the same attributes stated from the corresponding mathematical model and from the estimated parameters.

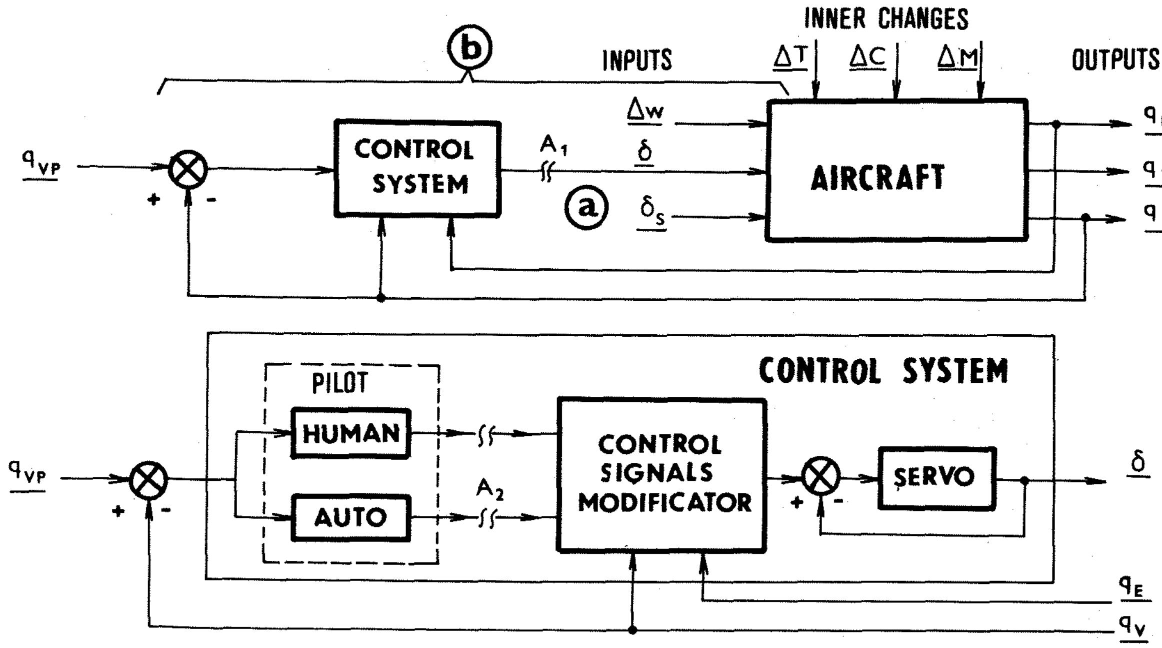
Besides the basic classification given above, the classes "aircraft performance" and "flying qualities" are in literature further divided into subclasses, groups and subgroups. Denominations of these classes and subclasses are at the same time the denominations of the respective phenomena.

The topics of the class "aircraft performance" are extreme values of the flight velocity of an aircraft centre of gravity (c.g.) and geometric and time characteristics of an aircraft c.g. trajectories. In the book (24) by Miele aircraft performance is further classified into "point performance" or "steady performance" and into "integral performance" or "unsteady performance". In the "point performance" a steady or quasi-steady motion of an aircraft c.g. is dealt with, for which the motion equations are algebraic (e.g. extreme velocities in level flight, rate of climb etc.). In the "integral performance" one deals with an unsteady motion which is described by differential nonpartial equations. The denomination "integral" is used because it concernes with a motion between two specified points of an aircraft trajectory which are in a sufficient distance of one from the other point, e.g. the motion of an aircraft at take-off or landing. Besides basic performance, enclosing maximum and minimum velocity of flight, rate of climb, ceiling, range and endurance, and take-off and landing distance, in the reference (17) also a subclass of general performance characteristics is considered which is called "manevrennost" in Russian and could be put in English as "mobility". This subclass is determined by curves families describing the dependance of load factor components on the Mach number.

The class "flying qualities" deals with characteristics of an aircraft motion, both translational and rotational, which follow external or internal disturbances of a given state of flight or follow disturbing a flight equilibrium by means of aircraft controls. They are thus qualities which characterize preciseness, easiness and security when utilizing aircraft performance by pilot to reach a given flight goal, see e.g. (51) by Mooij. With proceeding time the topics of this class were affected strongly by development of control theories studied in cybernetics and by progress in system engineering. In recent years an aircraft is being considered to be a controlled system comprising a human pilot or autopilot and other control devices, stabilizing or damping ones or devices which are often called "active control", see ref. (51) and figure 2.

From the early beginnings of flight mechanics development this class "flying qualities" was used to be divided into subclasses "stability of flight" and "flight control qualities", see e.g. (1, 2, 3, 4, 6, 7, 10, 12, 18, 29, 41, 43, 45) and others. In the first subclass one deals with a free motion of an aircraft after an external or internal disturbance of an equilibrium flight without this motion being affected by pilot's controls. A natural motion of an aircraft is thus considered. In the second subclass an aircraft motion forced by pilot's controls is considered. Already from the beginning the subclass "flight stability" was based on the elaborated stability theories, especially by Ljapunov, see e.g. ref. (33). In stability theories there was stated a stability definition which is used even now and which in a simplified form reads: "A body motion is considered to be stable when after a disturbance it recoveres and approaches without any external intervention nearly the original motion". The stability is characterized by damping and by oscillation period or frequency when the motion is a damped oscillating one. The subclass "flight control qualities" was developing with control theories development as in terminology as in its topics, see e.g. ref. (4, 6, 18, 21, 22, 29, 45, 51). The flight control qualities are characterized by static and dynamic effects of controls on an aircraft motion.

Even in older works of flight mechanics the flight stability was used to be divided into "static" and "dynamic" stability. This classification however cannot be considered to be correct from the stability



COLUMN MATRICES: $\underline{\delta}$, $\underline{\delta_S}$ - controlling inputs of primary or secondary controls. $\underline{\Delta w}$ - disturbing inputs-gusts. $\underline{\Delta T}$, $\underline{\Delta C}$, $\underline{\Delta M}$ - inner changes or disturbances of propulsion forces, aircraft configurations, aircraft mass or mass distribution. $\underline{q_V}$, $\underline{q_R}$, $\underline{q_E}$ - outputs: aircraft gross motion, rigid or elastic aircraft parts motions. $\underline{q_{VP}}$ - desired state of aircraft motion.

FIGURE 2 - SCHEME DIAGRAM OF AIRCRAFT SYSTEM: a) OPEN LOOP (IN POINTS A_1 OR A_2); b) CLOSED LOOP

theories point of view because there exist just one stability that means the dynamic one. "Static" stability is characterized by coefficients of static stability, longitudinal and directional, which belong to aerodynamic derivatives. Being just aerodynamic concepts they give an information about existence of a restoring force or moment originated after a flight condition disturbance. Existence of the static stability is thus a necessary condition but not a sufficient one for the flight stability to be assumed.

According to Malkin (33) one can consider the stability of a steady flight or of an unsteady one controlled by a program. If the initial flight is a rectilinear one the stability can be, as a rule, divided into longitudinal and lateral ones (but not transverse one). In curvilinear flights interactions can exist between longitudinal and lateral quantities which do not admit of the foregoing dividing of stability.

According to (33) an initial flight disturbance can be "small" and one speaks about a "stability in the small", or it can be "large" and then one speaks about a "stability in the large". The stability in "the small" is of great importance because it allows to linearize equations of motion and therefore to simplify a theoretical solution and also an experimental ascertainment of stability characteristic.

A flight condition disturbance can be one at the beginning of an experiment (a corrupted flight) or disturbances may be continually acting as in a flight in turbulent atmosphere (continually disturbed flight).

In references (7, 17) there is distinquished between a stability with fixed and free motivators while in the book (10) the author distinquishes between a stability with fixed and free pilot´s controls. The relation to the pilot´s controls is convenient from a pilots view-point whilst the relation to the motivators concernes the aerodynamic point of view. The distinquishing between fixed and free pilot´s controls or motivators is useful when judging the stability by means of control forces or by means of control deflections. In flight, however, even with a simple control system a motion of a motivator or of pilot´s control is affected by friction and play in the control system. These circumstances will get even more complicated when a booster (22), a stabilizing or damping device or active control system (51) are incorporated in the control system, see fig. 2.

The cybernetics influence on stability theories shows itself in recent years in the fact that an airplane is considered not only as an open loop as it was done in past time but also as a loop closed by pilot, human or automatic, see e.g. (29,

45) and fig.2. The work (32) deals with transfer functions of a human pilot, where also results of correlation research between stability characteristics (damping and period of oscillations) and pilot opinion rating (POR) by means of Cooper's scale are also given.

The influence of control theories is the most obvious one in opinion on flight control qualities. Already in text books from 60th, see e.g. (17, 18, 22, 29), an aircraft is considered to be a mechanical controlled system having control input signals and aircraft response output signals.

Ostoslavskij in (29) concernes with two sets of controllability problems: controlling of an aircraft flight on a programmed trajectory and controlling to eliminate effects of random disturbances on a flight equilibrium. The both sorts of controlling are performed by primary controls and throttle is used only to control an aircraft on a trajectory given by a program. At some manoeuvres the control process can be divided into specified elements, at other manoeuvres all the controls are used simultaneously and complexly, as it is e.g. at take-off and landing or in spin, see e.g. (12, 48). Likewise stability, even flight control qualities may be divided into longitudinal and lateral ones, eventually also into transversal and directional ones.

An other approach, which is often used in basic cases of control qualities, results from distinguishing of pilot's controls effects upon static and dynamic ones, see e.g. (12, 17, 18). To the static effect is adjoined "static flight control qualities", in English often "controllability", in French "manoeuvrabilité" and to the dynamic effect is adjoined "dynamic flight control qualities", in English "manoeuvrability", in French "maniabilité". The control system activity can be described either by pilot's control or motivator deflections or by control forces or hinge moments of motivators. From a pilots point of view control forces are of the greatest importance. Some recently used concepts and characteristics (e.g. the translation from Russian "following pilot's controls") are now being often replaced by concepts and characteristics from control theories, see e.g. (26, 32, 34).

The static flight control quality is characterized by changes of control deflections or control forces which are necessary to provide new steady flights different from the original ones, see e.g. (7, 9). The dynamic flight control quality is characterized by dynamic responses of an aircraft to standard shapes (step, impulse or harmonic) of time dependent courses for control deflections or control forces at a specified initial steady flight conditions. When an input control quantity course is of the step shape then the response is called the transition function (indicial admittance). When the time dependent course of an input quantity is harmonic then the response is determined by a frequency transfer function, see e.g. (52). Characteristics of response functions are defined in control theories.

The effect of internal changes of an aircraft configuration on its steady flight, see fig. 2, can be considered to be again static or dynamic. The static effect of an internal change (e.g. lowered undercarriage) is characterized by a deviation of the new steady flight, if it exists, or by a control force change, the original steady flight being unchanged. This quality is in German called "Lastigkeit", see (54), and in Czech "tíživost". In the case that in new conditions an aircraft can be trimmed for a short time by primary controls, a further problem of "control trim ability" by means of secondary controls emerges, what means an ability to make the respective control force permanently zero. Dealing with a dynamic effect of internal aircraft changes the transition aircraft motions are studied at various conditions.

When solving problems of aircraft flight stability and of flight control qualities, not only the term "aerodynamic derivative" but also other terms are used, e.g. the aerodynamic term "aerodynamic center" and flight mechanics term "neutral point", "dynamic point", "static and dynamic margin", "control dicriminants", see e.g. (31, 34, 66). At certain value of Strouhal number (reduced circular frequency) considering nonstationary flow around the airframe can get necessary. Due to this fact instead of aerodynamic derivatives the aerodynamic frequency transfer functions must be used, see e.g. (52).

In Airworthiness Requirements in the chapter "Flight" a classification of flight characteristics into "performance" and "flying qualities" is usually used. But there is not enclosed a precise specification of these two classes. As for equivalent terms in various languages a unique explanation of some terms is not assured, e.g. "mechanics of flight" and "dynamics of flight". It is very surprising for instance that terms derived from the word "manoeuvre" have different significations in French, English and Russian. The "static flight control quality" is called in French "manoeuvrabilité" and in English "controllability", the "dynamic flight control quality" is called in French "maniabilité" and in English "manoeuvrability". "Manevrennost" is in Russian used for "mobility". In French and English a general term for "flight control qualities" is quite missing.

3. Problematics of classifying based on predicate analysis

During classifying one can proceed intuitively by considering similarity of objects and phenomena. But there suits more an intentional approach by a convenient classification method.

In flight mechanics classification one concernes not with distinquishing objects and phenomena by quantitative scales but

Set of predicates: p or p, q (n = 1,2)				
p	class	p	q	class
1	1	1	1	1
0	2	1	0	2
$m = 2^n$		0	1	3
		0	0	4

TABLE 1 - PREDICATE VERITY TABLE

with classifying by qualitative description of phenomena. To this aim the classification method is convenient which utilizes laws of statement analysis based on Boolean algebra and theories of sets. Such a method was reported by Watanabé in 1962, see (30).

For a set of searched phenomena it is possible to propose according to the classification aim a set of statements which describe properties of the classified phenomena or relations between them. In statement analysis such statements are called "predicates". An n number of them determines an m number of classification classes being at most 2^n. These classes should be of such a property that elements comprised in one class can not be enclosed in another class because the classes are disjunctive subsets of a set of searched objects or phenomena.

If a predicate is veritable its verity value is 1, if is not veritable it has the verity value 0. In the most simple case which is dealt with in this paper one can suffice just with basic predicates without considering composed predicates that can be created from the basic ones by logical operations. An example of a "verity table" for sets of predicates at n = 1 and 2 is given in the table 1. The classes describe independent phenomena just when matrices from predicates values are regular. In this example the fourth class is thus dependent on the first one.

A method of predicate analysis is applied in the following chapters in the way that there is proposed firstly a classification point of view for to create predicates for the considered phenomena set. In some cases even more than one classification view point can be considered. Then classes are being proposed for various independent combinations of verity values

Science or discipline	Classification view-point		Predicates p, q, r (considered)	Verity p	Verity q	Verity r	Discipline or class	
Flight mechanics	basic quantities	p	space and time	1	0	-	flight	kinematics
		q	mass	1	1	-		dynamics
	working methods	p	theoretical methods	1	0	-	theoretical	flight mechanics
		q	experimental methods	0	1	-	experimental	
Flight kinematics	basic quantities	p	position and orientation	1	0	-	position and orientation characteristics	
		q	time changes	0	1	-	time kinematic relations	
Flight dynamics	motion model	p	motion of aircraft as a mass point	1	0	-	performance	
		q	motion of aircraft as a nonrigid bodies system	0	1	-	complex flying qualities	
	user's needs	p	characteristics of aircraft trajectory	1	0	-	performance	
		q	facility and safety of flight operation	0	1	-	complex flying qualities	
Experimental flight mechanics	gnoseological	p	determining of flight characteristics by measurements	1	0	0	flight measurements	
		q	model parameter estimation from measured flight data	0	1	0	parameter estimation	
		r	identity verification of aircraft and its model behaviour	0	0	1	identity verification	

TABLE 2 - BASIC CLASSIFICATION IN MECHANICS OF FLIGHT

of predicates.

4. Basic classification in flight mechanics

The view-points of a basic classification in flight mechanics and the respective predicates are given in the table 2. As for flight mechanics of an aircraft there is proposed with relation to classical mechanics to use as classification view-points the enclosed basic quantities and also the utilized basic working methods. In classification of flight dynamics (which is considered to be a more narrow concept as is flight mechanics) also two points of view are used which are the model (equations) of motion and the users needs. But in this case the both ones result in the same classes. For disciplines and classes following from the considered predicates some short definitions are further proposed.

Flight mechanics of aircraft is an applied science which deals with motions of an aircraft in atmosphere. It is divided into "flight kinematics" and "flight dynamics". Besides that it is alternatively divided into "theoretical" and "experimental" mechanics of flight of the aircraft.

Flight kinematics being a part of aircraft flight mechanics studies problems of an aircraft motion considering just space and time without account to causes of motion. It is divided into classes: "aircraft position and orientation characteristics" and "kinematic relations".

The first class comprises particularly problems of coordinate systems in flight mechanics, problems of determining orientation of an aircraft in space and problems of transforming components of vector or tenzor quantities from one to another coordinate system.

Flight dynamics being a part of aircraft flight mechanics studies problems of an aircraft motion with account to causes of motion which are forces and moments acting on an aircraft being considered as a nonrigid mass bodies system. This class is divided into two subclasses: "aircraft performance" and "complex flying qualities".

Theoretical flight mechanics is a part of aircraft flight mechanics which concernes with the laws of aircraft motions and with general properties of these motions. An aircraft is considered as a nonrigid bodies system. This class comprises hypotheses creation of mathematical models for aircraft motions too.

Experimental flight mechanics is a part of aircraft flight mechanics in which aircraft behaviour is determined by experimental methods. From gnoseological view-point this discipline can be divided into three classes: "flight measurements", "flight model parameters estimation" and "identity verification of behaviour of an aircraft and of the respective model". These three classes are in fact also stages of an identification process of the chosen attributes of an aircraft flight and of the respective model, see (52).

The class "flight measurements" encloses from the methodical view-point the following subclasses: "instrumentation for flight measurements", "flight measurement and evaluation methods" and "reducing of measured data to standard conditions". According to the measured objects this class "flight measurements" can be divided also into measurements on an aircraft, on a dynamically similar model and on a flight simulator. The class "estimation of flight

Class or subclass	Classification view-point	Predicates p, q, r			Verity p	Verity q	Verity r	Subclass or group
Performance	flight trajectory interval	p	considered	point of steady flight	1	0	-	point performance
		q		large trajectory interval of unsteady flight	0	1	-	integral performance
	importance for flight operation	p		basic performance characteristics	1	0	-	basic performance
		q		extreme geometrical and time characteristics of trajectories	0	1	-	mobility
Complex flying qualities	motion model	p		gross motion of aircraft	1	0	-	flying qualities
		q		fine motion of aircraft elastic parts	0	1	-	aeroelastic qualities
Flying qualities	motion model	p		free (uncontrolled) aircraft motion after a disturbance	1	0	-	flight stability
		q		forced aircraft motion by pilot's controls	0	1	-	flight control qualities

TABLE 3 - CLASSIFICATION IN FLIGHT DYNAMICS

model parameters" (from data measured in flight) can be divided according to types of methods used which differ due to necessary informations a priori.

A survey of the basic classification in flight mechanics can be seen also from the figure 1 which amends the table 2.

5. Classication in aircraft flight dynamics

In contradistinction of the basic classification in flight mechanics as in a science discussed in chapter 4, in the present chapter the classification of phenomena in flight dynamics is dealt with according to their properties. The classification view-points and the respective predicates are given in tables 3 and 4.

In the class "aircraft performance" the predicates are proposed on the one hand from the view-point of a flight trajectory interval and on the other from the view-point of flight operation. In the class "complex flying qualities" and in the subclass "flying qualities" the view-point of an aircraft motion model is considered. In the group "flight stability" one can consider four alternative view-points for predicates proposing. In the group "flight control qualities" the same predicates and subgroups result from the pilot's opinion view-point as from the view-point of the manner of using primary and secondary controls. In the subgroup "basic flight control qualities" predicates are proposed from the controls effect view-point and in the subgroup "trimming ability" from the point of view of the sort of controls used to trim.

To the classes, subclasses, groups and subgroups resulting in the tables 3 and 4 from the considered predicates short definitions are proposed as follows.

<u>Aircraft performance</u> denotes kinematic characteristics of flight trajectories traced by an aircraft of given mass and configuration, at a given propulsion thrust and in given atmospheric conditions. Here an aircraft can be considered to be a mass point. Aircraft performance is interesting for aircraft users of all sorts.

Subclass or group	Classification view-point			Predicates p, q, r	Verity p	Verity q	Verity r	Group or subgroup
Flight stability	motion model	p	considered	open loop system	1	0	-	open loop stability
		q		closed loop system	0	1	-	closed loop stability
	sort of disturbance	p		initial disturbance, small or large	1	0	-	stability of corrupted flight
		q		continually acting disturbances	0	1	-	stability of continually disturbed flight
	sort of initial flight	p		initial steady flight	1	0	-	stability of steady flight
		q		controlled flight according to the program	0	1	-	stability of programmed flight
	pilot's controls state	p		fixed pilot's controls	1	0	-	stability with fixed pilot's controls
		q		free pilot's controls	0	1	-	stability with free pilot's controls
Flight control qualities	pilot opinion or control operation manner	p		simple flight conditions	1	0	0	basic control qualities
		q		complex manoeuvres	0	1	0	complex control qualities
		r		ability to trim inner perturbations	0	0	1	trimming ability
Basic control qualities	control effect	p		static effect of primary controls	1	0	-	controllability
		q		dynamic effect of primary controls	0	1	-	manoeuvrability - dynamic responses
Trimming ability	sort of control used to trim	p		utilization of primary short-term control	1	0	-	flight conditions trimming
		q		utilization of secondary long-term control	0	1	-	control force trimming

TABLE 4 - FLYING QUALITIES CLASSIFICATION

"Aircraft performance" is divided into "point (local) performance" and "integral performance" and on the other hand into "basic performance" and "mobility".

Point performance denotes momentary characteristics of an aircraft flight trajectory at a steady or quasi-steady flight of an aircraft of a given mass and configuration and at a given propulsion and atmospheric conditions.

Point performance comprises extreme values of flight velocity, maximum rate of climb and minimum rate of descent, further minimum values of curves radii and maximum values of centripetal acceleration or of load factor.

Integral performance denotes kinematic characteristics of specified flight trajectory intervals between some initial and final points at a given law of time dependance of flight kinematic quantities and at a given state of aircraft, propulsion and atmosphere.

It encloses for example take-off and landing distances, ceiling, range and endurance. Further also minimum time for curves needed to change flight course by a given angle, extreme geometric and time characteristics of various aerobatic manoeuvres belong to integral performance.

Basic performance denotes kinematic characteristics of flight trajectories which are of importance for aircraft operation.

Mobility denotes extreme geometric and time characteristics of flight trajectories at given flight conditions which are not enclosed in basic performance and are possible and allowed in aircraft operation. They are for example maximum values of acceleration or of operational aircraft load factor.

Complex flying qualities are characterized by motion qualities of an aircraft considered as a system of rigid or nonrigid bodies which affect security, precision, easiness and agreability of flight operations and which are therefore of interest for pilots, passengers and other members of crew.

They comprise gross translational and rotational aircraft motions and fine relative motions of rigid and nonrigid parts of an aircraft.

One can divide "complex flying qualities" into "flying qualities" and "aeroelastic qualities" of an aircraft. This classification is possible when even one uses a mathematical model which describes contemporarily both sorts of qualities including their interactions.

Flying qualities of an aircraft are characterized by properties of a "gross" motion of the aircraft as a whole, which are translational and rotational, free or controlled, and which affect security, easiness and agreability, with which an aircraft is able to perform its flight task.

They concern with responses to external or internal disturbances of flight equilibrium and with aircraft responses to controlling its flight by means of primary and secondary controls. From this viewpoint one can divide "flying qualities" into "flight stability" and "flight control qualities".

Aeroelastic qualities of an aircraft are characterized by motion qualities of elastic parts of an aircraft which affect flight security, easiness and precision of its controlling.

Aeroelastic qualities have a static part which shows itself as distorsion of elastic elements with a respective effect on flight control qualities and also a dynamic part which affect life of an aircraft structure and which can result in undamped oscillations of elastic parts of an aircraft and can threaten its integrity.

Flight stability of an aircraft is characterized by qualities of aircraft responses to external or internal disturbances of flight equilibrium.

A stable time dependance of an aircraft response is characterized by the fact that deviations of values of flight kinematic quantities due to an equilibrium disturbance decrease without pilots activity.

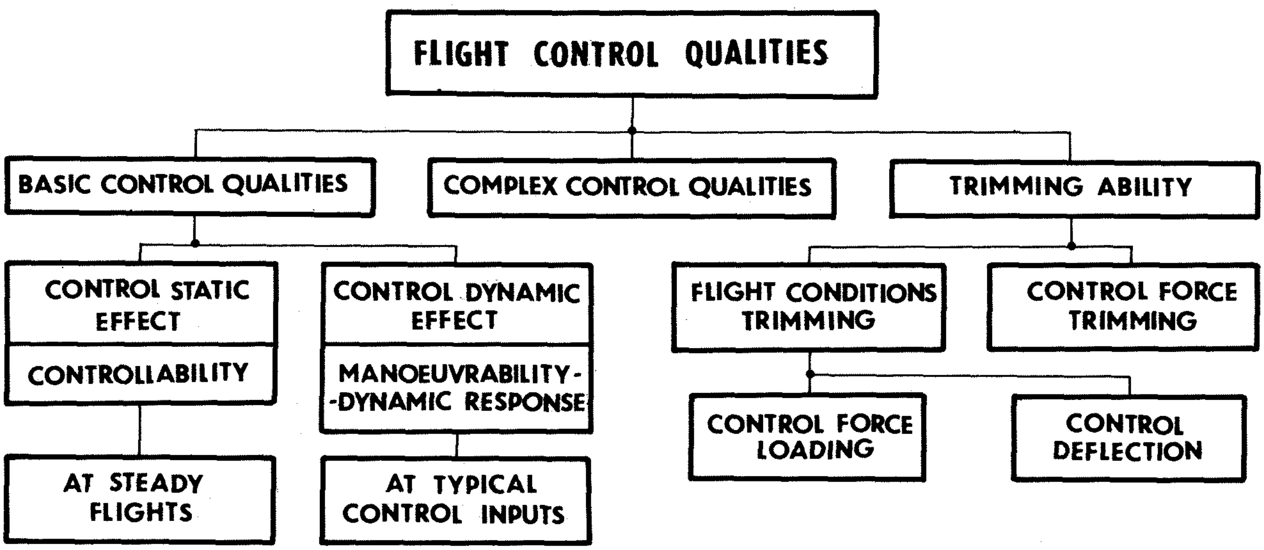


FIGURE 3 - SCHEME DIAGRAM OF FLIGHT CONTROL QUALITIES CLASSIFICATION

According to Lagrange and Ljapunov there is presumed that deviations after a disturbance will become permanently less than any little value ε a priori chosen to which relates maximum allowed initial deviation h where $\varepsilon < h$. Flight is assymptotically stable when a flight deviation after a disturbance diminishes to zero, i.e. when the "disturbed flight" approaches asymptotically to the "undisturbed flight".

According to view-points given in table 4 flight stability can be divided into four subgroups as follows: a) stability at open and closed loop of an aircraft system; b) stability of a corrupted flight and stability of a continually disturbed flight; c) stability of a steady flight and stability of a flight controlled by a program; d) stability with fixed and free pilot's controls.

Item b) comprises flight in turbulent atmosphere where responses occur to random gusts without pilot's action at an open loop or with controls activity at a closed loop (autopilot, gusts damping). At continually acting disturbances the flight stability is assured when the respective flight is assymptotically stable.

As for an initial disturbance it can be small or large. Thus a "stability in the small" or a "stability in the large" can be considered, see chapter 2.

As for item c) at a straightline steady flight the stability can be divided into "longitudinal" and "lateral" ones, but the static stability coefficient is said to be "longitudinal" and "directional".

In the item d) this classification looses its importance if in the control system a irreversing element, as e.g. servocontrol, is enclosed.

Flight control qualities are characterized by properties of an aircraft motion which is forced by the pilot by means of the aircraft controls at minimum needed workload of the pilot.

In function of input control signals one can consider deflections of pilot's controls or pilot's control forces acting on the same which are decisive from the pilot's standpoint.

The purpose of aircraft controls is of two kinds: firstly to lead an aircraft on a prescribed trajectory and secondly to eliminate unwanted effects of external and internal disturbances of aircraft equilibrium.

"Flight control qualities" can be divided into "basic control qualities", "complex control qualities" and "trimming ability".

Basic control qualities of an aircraft flight are characterized by properties of aircraft responses to simple controlling actions at steady or quasi-steady flights at a given state of aircraft, propulsion and atmosphere. These responses can be considered according to their character to be equivalent to static or dynamic effects of controls.

Therefore the "basic control qualities" of an aircraft flight can be divided into "static effect" of controls which can be called also "controllability" and into "dynamic effect" of controls called often also "manoeuvrability" or "dynamic response".

Controllability or static controls effect is characterized by ability of an aircraft to fly at various steady or quasi-steady flights by means of primary aircraft controls at a given state of aircraft, propulsion and atmosphere. The static effect of primary aircraft controls is dealt with.

Controllability is limited by maximum allowed control forces on pilot's controls, by extreme motivators deflections and by dangerous flight states (stalling, critical flight velocity).

As a measure of controllability one can consider e.g. at a restilinear steady flight a control force change needed to a 10 per cent change of flight velocity or at a quasi-circular flight in vertical plane it can be a control force change needed to produce the load factor 1 g.

But extreme values of kinematic parameters of steady flights from the set of possible steady flights belong into the class performance.

Manoeuvrability or dynamic controls effect is characterized by properties of aircraft dynamic responses to typical time dependances of control deflections or of control forces on individual primary pilot's controls at a given state of aircraft, propulsion and atmosphere. As a typical control input one can use a step function, impuls function or a harmonic function. Besides the wanted primary effect also an undesirable "secondary" effect can take place (e.g. by deflection of ailerons).

A response quality can be evaluated by the form of transient function or of frequency transfer function of kinematic quantities describing an aircraft response according to the usual criteria from control theories.

Complex control qualities are characterized by aircraft responses having a shape of various complicated manoeuvres resulting from contemporary deflections of several controls where these deflections are expressed by more complicated time functions. Here e.g. control qualities at takeoff and landing, at aerobatic manoeuvres, at stall and others are dealt with.

Trimming ability is characterized by possibility to trim the effect of internal aircraft changes by means of primary and secondary controls. As an internal aircraft change one can consider a propulsion thrust disturbance, a change of geometric configuration or a change of aircraft mass and of its distribution.

Trimming ability can be divided into "flight conditions trimming" and "control force trimming".

Flight condition trimming ability is characterized by a possibility to trim a corrupted flight equilibrium due to an internal disturbance the trimming being done by short-term utilization of primary control.

A control force observed by the pilot on pilot's controls after a re-establishment of the original or next possible flight condition is a measure of "control force loading" (in German "Lastigkeit", in Czech "tíživost"). This control force loading can be limited by requirements. Similarly, this can be said about deflections of primary controls, see figure 3. Control force trimming ability is characterized by a possibility to diminish control forces on primary pilot's controls to zero by long-term utilization of secondary controls. The mentioned control forces have resulted from trimming an internal disturbance of aircraft equilibrium or after changing the original steady flight.

In conclusion of this chapter some supplementary comments are amended.

Steady or quasi-steady flights are concerned with in "point performance" and in "static effect of primary controls" or "controllability". But topics of "point performance" are attainable extreme values of kinematic quantities describing trajectories which are belonging to the set of possible steady flights by effect of aircraft controls. In "controllability" on the other hand one deals with conditions at which various steady flights can be reached from the standpoint of controlling. This means that necessary changes of control forces and pilot's controls deviations are here considered. Therefore "point performance" is not identical with "controllability".

According to mutual relations of flying and aeroelastic qualities of an aircraft the both sorts of these qualities can be calculated either separately from the beginning or simultaneously as "complex flying qualities" by means of one mathematical model including mutual interactions. But at the both approaches the "complex flying qualities" can be divided into "flying qualities" and "aeroelastic qualities" when utilizing the results in practise to evaluate an aircraft behaviour.

Aircraft responses are considered with both in "flight stability" and in "flight control qualities". But in both of these cases the causes of responses are of quite different nature. Thus it is necessary to supplement the term "response" always by a detailed description of this cause.

6. Conclusion

The proposed classification in flight mechanics and the suggested definitions of basic terms in flight mechanics are only one of possible solutions. In the proposal the historical evolution of flight mechanics and of sciences applied are taken into account. There is also left space for further evolution in flight mechanics resulting from progress in aircraft development. Sometimes it was necessary to use English terms corresponding by vocabulary to the semantic sense of described phenomena without any intention to inforce their utilizing in the English terminology.

In preparing the proposal of classification the predicate analysis have been chosen to give as far as possible a time invariant frame for progressing flight mechanics.

The classification has been performed in two stages. The first stage comprises a basic classification of flight mechanics being a scientific discipline. The second stage encloses the classification of phenomena being objects of studies in flight dynamics, i.e. aircraft performance and complex flying qualities.

The goal of the classification and of the given definitions for basic terms is to facilitate mutual understanding of specialists from various countries and different aeronautical branches at aircraft searching and developing and especially at interpreting airworthiness and other aeronautical requirements. Besides this the classification should create a basis when producing criteria evaluating quantitatively aircraft performance and complex flying qualities.

The importance of a convenient classification in flight mechanics can be seen also from the fact that this classification has been included into the plan of international standardization by ISO with the aim to create a further part of the standard ISO 1151 "Terms and symbols in flight dynamics".

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