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The Norris Brothers Ltd. morphological approach to engineering design – an early example of applied morphological analysis

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Abstract: One of the most interesting examples of early application of morphological analysis to engineering is the work of the British Norris brothers, who in the 1960s worked with the speed racer Donald Campbell to achieve several world records. In this paper, I will describe their work and its significance within its historical context as an early example of the "morphological approach" to actual engineering design.

Keywords: general morphological analysis; morphological approach, engineering design; Fritz Zwicky, modelling theory.

1. Kenneth Norris's view of morphological analysis

In September 1962, Kenneth Norris presented a conference paper "The morphological approach to engineering design,"[†] which describes the influence of Fritz Zwicky[‡] on his and his brother's engineering work. It is all the more remarkable in that it specifically describes how "the morphological approach" was applied by the Norris brothers' engineering firm in the design of a historical milestone in engineering design: the Bluebird K4 boat, and the record-breaking Bluebird CN7 car and Bluebird K7 hydroplane.

Kenneth Norris (1921–2005), an aeronautical engineer, was then in charge of the consulting, research, and development department in his company, and the leading authority on land and water speed record design. He had also headed teams that designed the first automatic seat belt mechanism, the first piezoelectric gas ignition system, and a very advanced method of transporting liquid methane in ocean tankers.

Norris had first come across Zwicky's work in 1951, when he read one of his papers, and his company started applying morphological analysis in 1958. As Norris put it, "it seemed at that time that the method could only be used for certain types of problems but subsequent applications have shown that possible use of the method is the rule rather than the exception".

In his paper, Norris outlined his interpretation of the morphological approach to engineering design, giving various examples to showcase its strengths and potential weaknesses. He also described the work done by his company using the morphological approach. So far, wrote Norris, Norris Brothers had applied morphological analysis to the design of ocean transport, cigarette lighters, track-ways, automobile automatic transmission, lightweight wheels, excavators, domestic heating, barge tanks, strains inside rubber, land storage tanks, and vehicle configuration (this latter category being presumable the one under which their work on the Bluebird vehicles fell).

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[†] Norris, K. W. (1963).
[‡] Norris quotes Zwicky (1947), (1948a), (1948b), (1951), and (1961).

Norris summarises the morphological method as applied to engineering design as follows:

Step 1. Set out the field of investigation
Step 2. Determine the basis of comparison
Step 3. Set out assumptions to be fed into the basis of comparisons
Step 4. "Reduce" the field of investigation by means of a process of elimination using the results of 2 and 3 and by any other means.

He then provides an illustration for the method. A transport system must have some equipment and a method of operation. Let these be the general parameters:

M = Method of operation
C = Equipment
A, B, D, E = Different methods of operation
F, G, H, J = Different types of equipment

So the method would be applied as follows:

Step 1. Set out the field of investigation
Descriptions of complete transport systems are given by:

A + G
B + F
Total 16

Which yields this matrix:

Parameter	"Step"				Describing
M	A	B	D	E	Method of operation
C	F	G	H	J	Type of equipment

Step 2. Determine the basis of comparison
This could be

$$\frac{y}{x} = \text{COST/TON PAYLOAD}$$

where y = COST (dependent variable)
and x = TURNOVER (independent variable)

Step 3. Set out the assumptions to be fed into the basis of comparison
Assume
Cost of M = $f(x)$, say "$a.x$" "$b.x$", etc.
and
Cost of C = a constant, say "f" "g", etc.

Then the cost of complete systems is given by:

$y = a.x + g$
$y = b.x + f$, etc. *Total 16*

from which y/x can be obtained for each system.

All 16 solutions can be worked out in this form and compared, but this might require too much work. Hence the following step.

Step 4. "Reduce" the field of investigation
In this example, B, E, H, and J may be unacceptable because of development cost, possibility of success, safety, and comfort respectively. The field is thus reduced as follows:

Parameter	"Step"	
M	A	D
C	F	G

2. Application of morphological analysis to the design of the Bluebird CN7

In his paper Norris also describes the way in which the morphological approach was applied to the problem of establishing a basis for classification of vehicles into fundamental types. At the time of publication of his paper, the Bluebird CN7 car was about to attempt the world speed record in the Automobile World Speed category. A basis for classification was thus required in order to establish whether the Bluebird CN7 complied with the International Automobile Federation regulations that defined the type of vehicle acceptable for an attack on this record.

The Norris Brothers engineering design team decided that vehicles should be defined in terms of their essential characteristics, namely:

- **Support:** the reaction to gravitational force.
- **Drive:** the force required to overcome resistance to motion and to change the vehicle's speed.
- **Stability:** the ability to maintain a given attitude along a given path.
- **Control:** the ability to change both attitude and path

They also decided that they should be categorised in terms of means by which they obtain their essential characteristics, namely:

- **Land**
- **Water**
- **Air**

These two sets of parameters constitute a matrix of possibilities that makes it possible to categorise a vehicle in terms of the degree to which its characteristics are derived from a certain means. For example, a car can be defined as a vehicle that derives its support, drive, stability, and control entirely from the land. Likewise, a boat is a vehicle deriving its support, drive, stability, and control entirely from water, and an airplane derives them all exclusively from the air.

On this basis (and omitting rockets and other space vehicles), Norris Brothers Ltd. generated a morphological analysis of self-propelled vehicle configurations that yielded the chart shown as Fig. 1, which includes a total of 81 possible vehicles. Of these only four are "thoroughbreds" – landborne vehicles A1A2A3A4 (cars), waterborne vehicles B1B2B3B4 (boats), and airborne vehicles C1C2C3C4 (cars), which derive all their essential characteristics from the same element. The rest of vehicles are mixed: for example, in the case of the Bluebird K7 Hydroplane built by Norris Brothers – B1C2B3B4 – the essential characteristics of support, stability, and control are obtained from the water, but the essential characteristic of drive is obtained from the air by jet thrust. On this basis, the Bluebird Hydroplane would be 3 parts a boat and 1 part an aircraft.

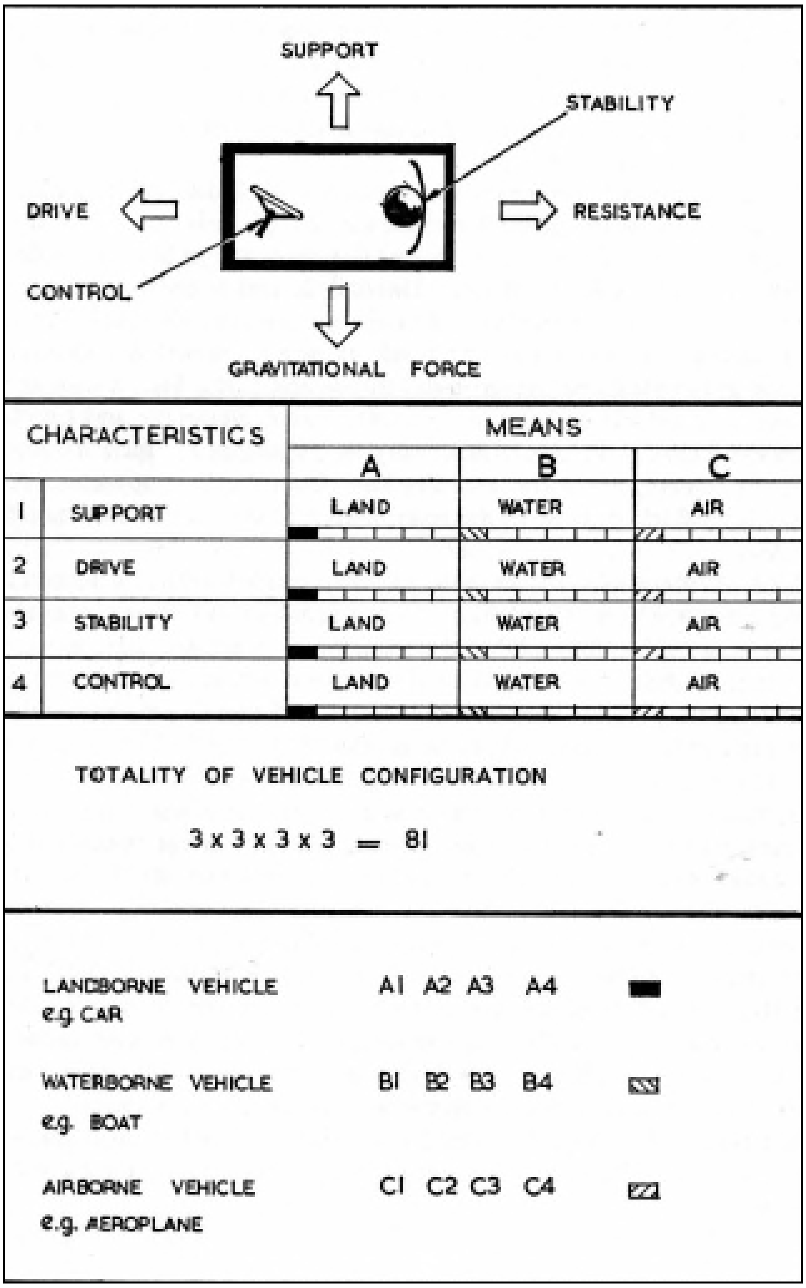

Figure 1. Morphological analysis chart showing the 81 possible means-characteristics configurations

The International Automobile Federation definition of a machine which might attempt the Automobile World Speed Record at the time of publication of the paper was the following: "A land vehicle propelled by its own means running on at least four wheels, not aligned, which must always be in contact with the ground, the steering must be assured by at least two of the wheels, and propulsion by at least two of the wheels". This made it possible to establish a basis for comparison between a vehicle authorised to attempt to break the Automobile World Speed Record as defined by the International Automobile Federation, and the two car prototypes on which Norris Brothers Ltd. had been working, the Bluebird CN 7/60 and the Bluebird CN 7/62. Assimilating the International Automobile Federation criteria to the parameters previously defined, the chart displayed as Table 1 clearly shows that both models met the requirements to attempt the record.

Characteristic		IAF Vehicle		Bluebird CN7/60		Bluebird CN 7/62	
1	Support	Wheels always in contact with ground	Land	Static weight on wheels at all speeds	Land	Static weight on wheels at all speeds	Land
2	Drive	Propulsion assured by at least two wheels	Land	Four-wheel drive	Land	Four-wheel drive	Land
3	Stability	Not mentioned	--	Tyre to ground forces	Land	Tyre to ground and tail fin forces	Land & Air
4	Control	Steering assured by at least two wheels	Land	Steering as-sured by two wheels	Land	Steering as-sured by two wheels	Land

Table 1. Assimilation of the International Automobile Federation criteria to the parameters defined

3. Norris's conclusions

In the conclusions to his paper, Norris states that the morphological approach in engineering provides a way to make unconscious processes conscious, and that it has the following benefits:

(i) It forms a sound basis for systematic design.
(ii) It removes prejudice to a certain extent.
(iii) It makes the invention process automatic.
(iv) It provides a single picture of all possible solutions, making it possible to consider one solution relative to another.
(v) It makes it possible to delegate work.
(vi) It provides by-products in the form of solutions that may be useful for purposes other than for the immediate problem.

He also states that the weakest part of the morphological approach concerns the rejection of unacceptable solutions[§].

Finally, he proposes establishing standard terms for the design process in general and the morphological approach in particular in order to aid education and discussion. He also proposes investigating the possibilities of computers to "separate and collate solutions… so that the elimination procedure becomes more automatic and less dependent upon the engineer's intuition"[**].

As Norris puts it regarding the link between engineering design and morphological analysis:

> "The normal process of designing, whether carried out intuitively or consciously, involves problem DEFINITION, ANALYSIS, SYNTHESIS and PRESENTATION. The morphological approach is not a replacement of this process but simply a very conscious way of carrying it out."

In this, as in other aspects, he seems to have been remarkably insightful and prescient regarding the nature and application of morphological analysis.

[§] This problem has been dealt with in contemporary GMA by means of a cross-consistency assessment that is precisely regulated using software applications. Cf. for example Ritchey (2006), (2011)

[**] Again, current GMA makes use of software programs to automatically visualise the problem space more clearly and to facilitate the cross-consistency assessment that classifies potential solutions according to their acceptability.

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