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H.H.Koelle:

The Influence Of The Layout Of The Satellite Vehicle On The Overall Cost Of The Project.

The artificial satellite project is one which must be regarded as the most important of all astronautical projects,due to the fact,that the construction of the satellite vehicle is the preliminary condition for the realization of more extensive space travel.

From this reason we can state that it is very likely that the space station or artificial satellite will be constructed sooner or later in spite of all technical and financial difficulties existing at present.This fact is well known and it is an open secret ,that the West and the East are both working on this project with the greatest energy.Therefore it seems to be necessary,that the astronautical and rocket societies should also engage themselves on a larger scale ,than has been done to date,in order to move the centre of gravity of this part of scientific research somewhat to the peaceful application of space travel.We have to make all efforts to remove the work on this project from the secret classification for the benefit of the human race.

The artificial satellite in general,with a special consideration of the influence of its layout on the overall cost of this project,will be discussed in this paper.

However,before entering into this discussion,we have to assume that all stability problems of the satellite can be handled.This is still an unsolved problem,which will be probably solved but might change the conditions considerably.

1.Definition

The space station or artificial satellite is a special vehicle of rocketry which has to be projected outside the atmosphere into a circular or eliptical orbit around the Earth,in which it would continue to move without any impulse,as long as the balance between gravity and centrifugal force is not disturbed by external forces.

2.Proposed uses of the artificial satellite

We will differentiate the following four groups in discussing the utilization of the satellite:

A.Preliminary work needed in the preparation for more extensive space travel projects,
B.Employment of base in connection with the realization of more extensive space travel projects,
C.Employments in connection with fundamental research in natural sciences,
D.Uses which have political,psychological or military influences.

Summarizing all individual tasks of these four groups the satellite will have during its entire existence the following detailed tasks, listed in a logical sequence:

1.To be an object for accurate determination of the orbit elements of bodies encircling the Earth,
2.Extra terrestrial exploration of the highest layers of the atmosphere,
3.Investigation of the behaviour of the human body under the influence of unreduced radiation from space,
4.Investigation of the behaviour of the human body at accellerations between 0 and 1 g ,
5.Investigation of the physiological and psychological behaviour of the human body in space,
6.Improvement of astronomical and astrophysical research by reducing the disturbing effects of the atmosphere on optical observations,

7. Improvement of investigations on cosmic rays,
8. Fundamental physical research such as the investigation of the behaviour of solids, gases and fluids under the physical conditions of space,
9. Fundamental chemical research such as the investigation of chemical reactions under the physical conditions of space,
10. Biological research including the investigation of the behaviour of plants under the physical conditions of space,
11. Long period observations of weather conditions, long period weather forecasting and study of the possibilities of artificially induced weather conditions,
12. Repeater station for short wave communication and television,
13. Central station for messages and emergency station for sea- and air-traffic as well as for isolated territories,
14. Observation station for the U.N. security forces,
15. Refuelling station for space vehicles,
16. Space vehicle building- and repair depo,
17. Control station and navigation aid for space vehicles,
18. Rescue station for space vehicles,
19. Investigation of the possibility of power supply on larger scale by means of solar radiation,
20. Medical clinic for special cases,
21. Expansion of human horizon by directing the thoughts of the individuals to space and towards the recognition of the necessity of an worldwide political organisation and to aid in its realization in order to form a harmonious political, cultural and economical life for all nations of the Earth.

3. <u>The task faced in the construction of the artificial satellite</u>

This task may be formulated as follows:
It is to find, to derive and to prove the most economical solution of the problem of constructing an artificial satellite.
By the most economical solution is meant the satellite of minimum cost to accomplish the required purpose.
Therefore we can hope for a realization of the space station project if the condition of economical balance is fulfilled. This condition is: Overall cost for the construction and for the maintenance of the satellite <u>equal to or smaller</u> than the financial returns or savings resulting from its use.

4. <u>Cost of the construction and maintenance of the satellite</u>

The overall cost of the construction of the satellite can be calculated by eq. (1). This is a formula which consists of 14 terms. The figures above the individual terms means: 1,2,3 cost of the development of the cargo rocket, satellite and equipment necessary for mounting 4,5 cost of the construction of the satellite vehicle parts and equipment on the ground; 6 construction cost of the passenger stages, 7 construction costs of the cargo stages, 8 construction costs of the booster stages taking into account the salvage of the returning stages to an extent of 50% of its original value, 9 fuel costs, which are calculated with 100 Dollar per ton, 10 cost for salvaging the booster stages, 11 general costs, 12 plant cost, 13 and 14 direct and indirect labor costs.
The formula for the maintenance costs eq. (2) is smaller because the development costs and the construction cost (to a certain extent) are not included here. These equations allow us to calculate the construction and maintenance costs for a specific satellite to a first approximation. They can take into account the progress of science and engineering by changing the constants and they are therefore, accurate for any possible design.

$$\text{(2)}\quad \overset{⑥}{K_U = K_{B(WP)} \cdot G_{N(WP)} \cdot N_{(P)} \cdot (1-\varphi\varphi^*)} + \overset{⑦}{K_{B(WL)} \cdot G_{N(WL)} \cdot N_{(L)}} +$$

$$\left[\frac{\$}{Mon}\right] = \left[\frac{\$}{t}\right] \cdot [t] \cdot \left[\frac{\text{Startzahl (Number of flights)}}{Mon}\right] [\div] + \left[\frac{\$}{t}\right] \cdot [t] \cdot \left[\frac{\text{Numb. of flights}}{Mon}\right] +$$

$$+ \overset{⑧}{K_{B(I \cdots III)} \cdot G_{N(I \cdots IV)} \cdot [N_{(P)} + N_{(L)} \cdot (1-\alpha\alpha^*)]} + \overset{⑨}{(N_{(P)} + N_{(L)})} \cdot$$

$$\left[\frac{\$}{t}\right] \cdot [t] \cdot \left[\frac{\text{Number of flights}}{\text{Month}}\right] \qquad + \left[\frac{\text{Number of flights}}{\text{Month}}\right]$$

$$\cdot [K_T (G_{6(I \cdots IV)} + G_{6\,ref\,(I \cdots III)})] + \overset{⑩}{B (N_{(P)} + N_{(L)}) \alpha} + \overset{⑪'}{A} + \overset{⑬'}{K_{L(a)}} + \overset{⑭'}{K_{L(i)}}$$

$$\left[\frac{\$}{t}\right] \cdot [t] \qquad + \left[\frac{\$}{\text{take-off}}\right] \left[\frac{\text{Numb. of flights}}{\text{Month}}\right] [\div] + \left[\frac{\$}{Mon}\right] + \left[\frac{\$}{Mon}\right] + \left[\frac{\$}{Mon}\right]$$

Having now obtained a general cost formula we are ready to discuss the specifications of the satellite and a specific design proposal which satisfies the proposed specifications.

5. Specifications of the satellite

The investigation of the construction problems of the space station shows that there exists a large number of conditions under which the station has to be built and operated. These conditions led to specifications, which - if all taken into consideration - determine the layout of the space station or satellite within close limits. To these axioms or specifications belong:

1. The components of the last stages of the cargo rockets must be used as components for the satellite in order to keep the cost as low as possible. The parts of the cargo rocket are already closely determined and this determines the components of the satellite to a large extent.
2. The time for a manned satellite has to be short, as the condition of gravity must be simulated as soon as possible. The ~~parts~~ lower limit of the construction time is fixed by the time required for assembling and by the desirability in the intrests of salvaging the booster stages.
3. The moments of inertia must have a symmetrical distribution for the sake of stability.
4. The masses have to be placed as near as possible to the rotation axis in order to place low stresses on the material of the connection elements.
5. The rotation axis must be vertical to the plane of the orbit for stability reasons.
6. The plane of rotation and the ecliptic must be identical, if the connection pipes between the central body and the outer ring are to be used for condensation purposes.
7. The satellite must have a control system by which all changes in motion and the plane of rotation as well as the velocity of rotation can be controlled.

8. The gravity, produced by centrifugal forces, should be between 0.5 and 1 g,
9. The mass of the satellite should be as great as possible to minimize perturbation effects. This requirement is limited for economic reasons.
10. The assembling work in space must be limited to the minimum due to physical, technical, ~~physiological~~ physiological and economic reasons.
11. All parts which have to be maintained must be accessible and if possible be located in pressured compartments.
12. Useful assembling- and transport vehicles for the construction and operation of the satellite must be available.
13. Security and rescue devices must be available in sufficiant numbers.
14. Extremly light construction is the most important demand in detailed construction. The safety factors must be calculated very accurately.
15. The shape and distribution of the individual compartmants is determined by the equipment which is required for the supposed uses.

As a result of all these specifications and considering the necessity for the most economic solution we can formulate now the following rule: "The construction of the satellite is very ~~likely~~ closely connected with the construction of the optimum cargo rocket to the satellite, hence the designs can not be seperated from each other".

6. Design study for an artifical satellite

In summarizing all the mentioned specifications we are led to a solution which might look like Fig.(1). The central body is connected by pipes with the outer ring in which the living cabins and laboratories are located. The station is rotating at 3.5 revolutions per minute which gives at a diameter of 60m an artifical accelleration of o.8 g. A lift is installed in each second pipe for the transport of persons and goods. The pipes also house the condensation device of the steam power plant.
The entire satellite consists of the following components, which will be common to all construction proposals of manned satellites to a fairly large extent:

A. Outer ring.-Consisting of the cabins of the last stages used as living rooms and laboratories, connected by air pressured gangways.
B. Connection pipes.- with the pipes themselves, the lifts, the condensation device and connection elements.
C. Central body.- This central body is shown in Fig.(2). It consists of 2 of the last rocket stages mounted together with two cabins as a control centre, the passenger exit cell, the material exit cell, the electrical network (with generator, batteries, light system), the highfrequency part (with transmitter, receiver, navigation aids, television etc.) the airconditioning equipment, the fire extinguisher, workshop and storage room, fuel station and containers, the laboratory free of gravity and of the steam power plant with two turbines. This steam power plant is shown in detail in Fig.(3) with the mirror, boiler (which rotates), the water container, the control system and the condensation system in the connection pipes. In addition, there is auxiliary equipment: space tractors, construction devices, emergency devices etc.

This design has the advantage of simplicity, of great lightness and greatest economy. By the using of rocket parts as components for the satellite we have to transport as a payload only half the weight of the station. This is a very important point. The overall transported payload for a manned satellite which previously was assumed to 500 to 1000 tons is reduced to not more than 100 tons. Consequently the overall cost are also reduced to 1/5 or 1/10 of the previously estimated values.
The proposed satellite will have the following mass distribution to a first approximation:

38 cabins	57.0 tons
36 connection gangways	3.6 "
8 connection pipes	20.0 "
central body	7.0 "
steam power plant	12.0 "
equipment	15.0 "
fuel reserve	15.0 "
water	3.0 "
space tractors	4.0 "
rescue vehicles	9.4 "
Total weight of satellite on ground ca.	150.0 tons

About 75 tons of the total 150 tons can be taken from the cargo rockets itself. Hence approximately 75 tons of construction material and about 10 tons of equipment are to be transported to the station. This is equal to the total payload of 24 cargo rockets with an individual payload of 3.5 tons each. By this means we may assemble 24 cabins of 38 required for the construction.

In order to determine the supplies required monthly we have to estimate the number of personnel employed on the station. The number of personnel is also important in the construction of the air conditioning system, so thus it must be considered. The number of persons for this station has been calculated to be between 50 and 65. (refer.1) If we now assume the supply for the station as 7.5 kg per man per day we must have therefore 3 cargo rockets with a capacity of 3.5 tons each per month for 50 men in addition. 1 more cargo rocket for equipment and spare parts and two passenger rockets per month are assumed for the regular traffic. That means that we have 12 more cargo rockets and 6 passenger rockets after a construction time of 3 months We then have 36 cabins available for the construction of the space station. The last two cabins (we need 38) are taken from the first two cargo stages which arrive during the last days of the construction bringing the first regular monthly supplies.

With these figures the cost of this design proposal will be calculate later, after a short discussion of some construction problems.

7. Individual construction problems

Under this paragraph a large number of problems are listed such as: the production of artifical gravitation, the electric power plant, the air conditioning system, the exit cells, steering and stability, The radiation protection, the design of space tractors (which were suggested by Dr. W. v. Braun (refer.2), the design of special tools and equipment, the assembling of the station, stress analysis of bodies under the physical conditions of space and others. These problems are partly discussed in detail in (refer.1). For an example we mention only the relation for determining the forces and demensiones of the connection pipes between the central body and the outer ring of the station.- The radius of the station for a certain accelleration and a certain number of revolutions is given by eq.(3):

$$R = \frac{b \cdot 60^2}{4 \pi^2 n^2} \quad [m]$$

This relation is shown in Fig.(4). The number of revolutions is indicated on the ~~[illegible]~~ abzisse and the radius of the satellite is indicated on the ordinate. The accelleration is chosen as paramete Using the symbols shown in Fig.(5) we find for the force acting in one connection pipe the relation eq.(4)

$$P = \frac{\pi^2 n^2 \sigma}{2} \left[\frac{M_1 r_1 + M_3 r_3}{450\, \sigma - \pi^2 n^2 r_3^2 \rho \gamma} \right] \quad [kg]$$

this equation can be simplified for materials with a high tensile strength (such as those between Dural and steel) to eq.(5)

$$P = \frac{\pi^2 n^2 (M_1 r_1 + M_3 r_3)}{900} \quad [kg]$$

For the wall thickness required we get eq.(6)

$$d = \frac{P \gamma}{2 \pi r \sigma} \quad [m]$$

and for the weight of one connection pipe eq.(7)

$$G_2 = 2 \pi l r d \gamma \quad [kg]$$

For our design proposal we get a weight of approximately 180 kg for one connection pipe.These formulae are derived in the report refer.(1).

An overall view of the proposed space station or artifical satellite during the construction might look like Fig.(6).

8.Discussion of the influence of the individual parameters on the overall cost of the project

After we have found a reasonable layout of the satellite and as we have already developed an advanced design of a cargo ship to the satellite (refer. 3),we now are able to make a rough calculation of the construction and maintenance cost according to eq.(1) and (2) which we have mentioned before.We present there the individual sums for development,construction,fuel supply etc.As a result for a construction time of 3 months we get with prices valid to day to a first approximation for our example the following cost:

cost for development	Dollar	$108 . 10^6$	= 20.8 %
cost for the construction of the satellite parts and equipment		$13. 10^6$	= 2.5 "
costfor the construction of the passenger stages without booster stages		$7 . 10^6$	≠ 1.4 "
cost for the construction of the last stages of the cargo rockets		$38 . 10^6$	= 7.3 "
cost for the construction and repair of the booster stages		$277 .10^6$	= 53.5 "
cost for fuel		$26 .10^6$	= 5.0 "
general cost		$12 .10^6$	= 2.3 "
cost for the salvage of the boosters		$14 .10^6$	= 2.7 "
plant cost		$20 .10^6$	= 3.9 "
wages(excluding construction)		$3. 10^6$	= 0.6 "
Total cost for the construction approx.	$	$518 . 10^6$	=100 %

This figure is strongly dependant on the design of the corgo ships and of the satellite itself.As the constants of eq.(1) are only estimated very roughly this figure can be regarded naturally only as a first approximation.But it can easily be corrected if more pain is taken in the calculation of the constants.-We can calculate the maintenance costs for the satellite according eq.(2) in the same way.We get as a result an amount of 40 to 50 Million Dollar per month,if the supply can be handled by 6 ships as assumed.

Looking at this table we can see which sums are the most important ones and must be consequently kept to a minimum.The cost for the development and the cost for the construction of the cargo and passenger ships take about 3/4 of the entire cost.This means that we are able to reduce the project costs to a large extent by concentrating our work on these items.For detailed discussion of these sums refer to refer.(1).

9.Procedures for the reduction of the overall cost

The overall cost is strongly influenced by a reduction of the overall weight ratio which is defined as the ratio of gross weight to the payload of the last stage.That means that we have to consider problems of detaile construction of the cargo ship in order to reduce the overall weight ratio.We can reach the same result if we take into consideration the fact that the use of vehicle parts in the satellite means a reduction of the flights required.Thus we have to work on the design of the cargo vehicle and the space station at the same time because they are definetely dependent on each other.The cost for the development will also be reduced by this work.
The investigation of materials and their application in this space travel project must be also pushed forward in order to reduce weights by means of very accurate and limited safety factors.
The overall cost can be influeneced further by well organized production and operation systems.A large number of problems are still to be investigated.
We must not forget however,that this project is still in its first stage of development which means that we can do a lot of work with pencil,slide rule and brain.This does not cost much money only time and good organized societies and working groups.The way which we should proceed is as follows:First,to create the foundation by solving the undeterminable number of individual problems; second,to prove that the artifical satellite would be of use for man(in order to get the money required); third,to start the construction which will undoubtly again produce undeterminable detailed problems which must be solved then.This way of development and improvement needs neccessarely long periods of time and this is the reason,why an artifical satellite does not yet exist and why it will not be realized for many years.

Regarding the question of proving the usefulness of the space station for our planet,we want to point out here only one fact:Undoubtly the construction of a space station or satellite will lead the human spirit and the thoughts of the individuals as well governments into space and enlarge their horizon.If now the probability of a third world war,which would cost at least 1 000 Billion Dollars and the life of millions of men,could be reduced by only 1% by this "space work",we would be able by the equivalent sum of more than 10 Billion Dollars to construct several satellites,a moon rocket and even to sent an expedition to the planet Mars.This is not the only useful figure we are able to mention but perhaps the most impressive one. Other reasonable figures are given in refer.(1).

10.Summary

The purpose of this paper was:

1.to give a clear definition of the arfifical satellite and ist uses;
2.to prove,that the construction of the optimum satellite cargo vehicle and the construction of the satellite itself can not be seperated from each other,according the principal proved here: "The cargo vehicle for the satellite and the satellite out of the cargo vehicle";
3.to prove,that the construction of the satellite is related to a number od physical,and technical and economical conditions;
4.to show,that it is possible to give a formula which allows us to calculate the construction and maintenance costs of artifical satellites and to discuss these relations for a specific design proposal of the cargo vehicle and the space station;
5.to show briefly the influence of the construction problems on the cost of the project and how these can be reduced;
6.to check the condition of economic balance for this project.

We are now able to assert after all these considerations that a reasonable economic balance will probably exist for this project as far as we can see at this early stage of development. This fact gives us the right and binds us to duty to draw to the notice of the public the need to devote more attention, more energy and more talent to this project, than has been done to date, as the space travel is and will ever be a cultural task of the mankind, which is pressing for realization.

References:
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(2) Dr.W.v.Braun " Das Marsproject", Sonderheft WELTRAUMFAHRT Umschau-Verlag, Frankfurt, Germany- Nov 1951 und Dr.W.v.Braun u.F.L.Neher "Menschen zwischen Planeten" (Das Marsprojekt), Bechtle Verlag, Eßlingen a.N. Germany, Feb. 1952
(3) Gesellschaft fuer Weltraumforschung e.V. Stuttgart, Germany Forschungsbericht Nr.8 : H.Hoeppner, H.H.Koelle "Die Optimale AS-Lastrakete zu einer Aussenstation in 1669 km Hoehe" Mai 1951

Symbols:

A	general costs	(\$ / month)
B	salvaging costs	(\$ / flight)
b	accelleration	(m / sec^2)
d	wall thickness	(m)
F	area	(m^2)
G	weights	(to)
I	plant costs	(\$)
K	costs	(\$)
l	length of pipe	(m)
M	mass	($kg\ sec^2/m$)
N	number of flights required	
p	, pressure	(kg / m^2)
q	time	(month)
r	radius	(m)
n	number of revolutions per minute	
ν	safety factor	

α recovering factor(takes into account the extent of recovering)

α^* correction factor(takes into account the extent of damage of the recovered vehicle component)

β salvaging factor of the satellite (takes into account that part of the satellite which is built out of components of the last rocket stage)

β^* correction factor (takes into account the additional work at the satellite due to salvaging)

γ salvaging factor of the cargo vehicle(takes into account that part of the returning stages which can be reused)

γ^* correction factor of the salvaging factor of the cargo vehicles(takes into account the repair and maintenance costs of the salvaged booster steps)

ω angle velocity ($^\circ$/sec)

σ stress (kg / m^2)

γ specific weight (kg/m^3)

ρ density ($kg/m^2\ s^2$)

Indices:

B	construction
E	development
N	netto
T	fuel
U	maintenance
5	payload
6	fuel
ges	total
res	reserve

(AS)	satellite
(H)	equipment and tools
(LR)	cargo rocket
(L)	life neccessities
L(a)	direct labor costs
L(u)	indirect labor costs
(P)	passenger rocket
(P)	passenger traffic volume

I, II, III, IV individual stages

Dèscription of figures:

Fig.1. Design proposal for an artifical satellite

A.cabins used as living rooms and laboratories
B.gangways
C.control rocket engines
D.connection pipes with ~~liftxand~~ condensation device
E.central body
F.connection pipe with lift
G.Mirror of the steam power plant

Fig.2. Central body of the artifical satellite

A.space tractor
B.entrance
C.airconditioning cell for passenger entrance
D.fuelcontainers
E.fuel container
F.water container
G.windows
H.spare parts and material storage
I.assembling and workshop
K.material entrance cell
L.connection pipe
M.lift
N.central
O.steam pipe
P.axle and bearing of the mirror
R.steam turbine
S.generator

Fig.3. Mirror of the steam power plant

A.Central body
B.center line of mirror axle
C.~~centraixnozzles~~ mirror
D.nozzles for control
E.guy rod
F.steam boiler
G.water container
H.engine for boiler
I.steam pipe

Fig.4 Variation of accelleration with the radius and number of revolutions of the satellite

Fig.5 Dimensiones of the satellite

Fig.6 Overall view of the satellite during the construction with space tractor

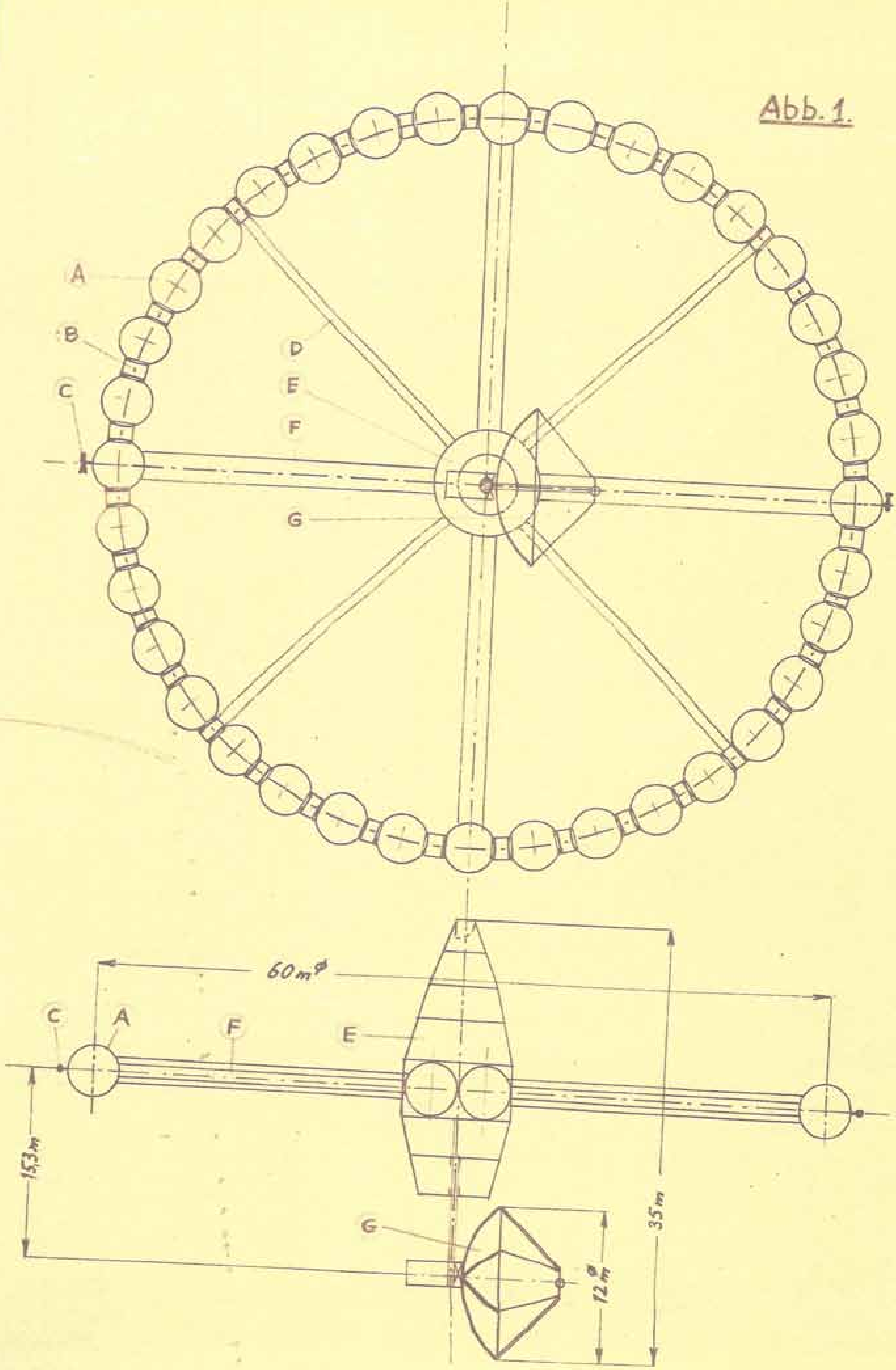
Abb. 1.
A
B
C
D
E
F
G
60 m ⌀
C
A
F
E
15,3 m
G
35 m
12 m ⌀

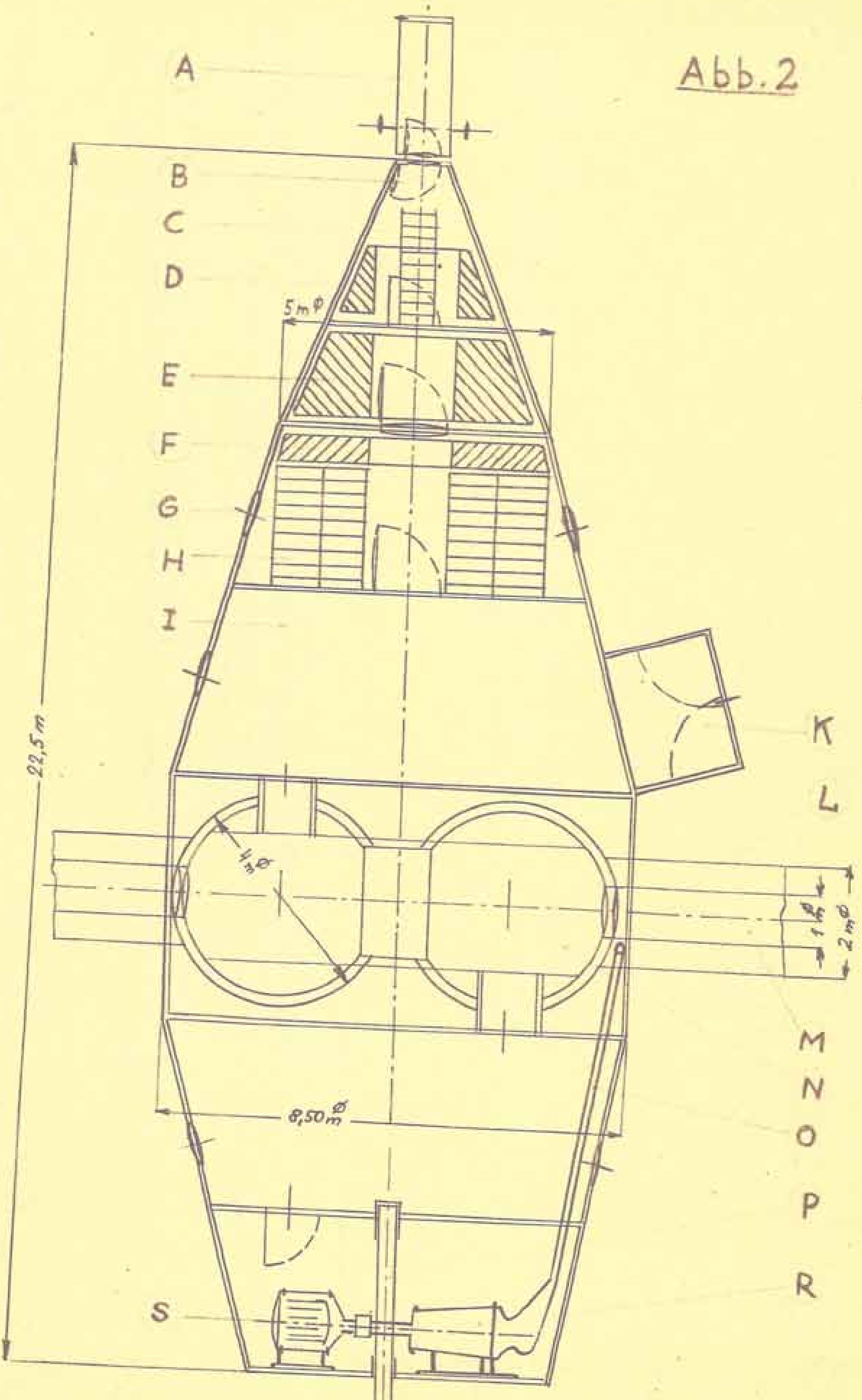
Abb. 2
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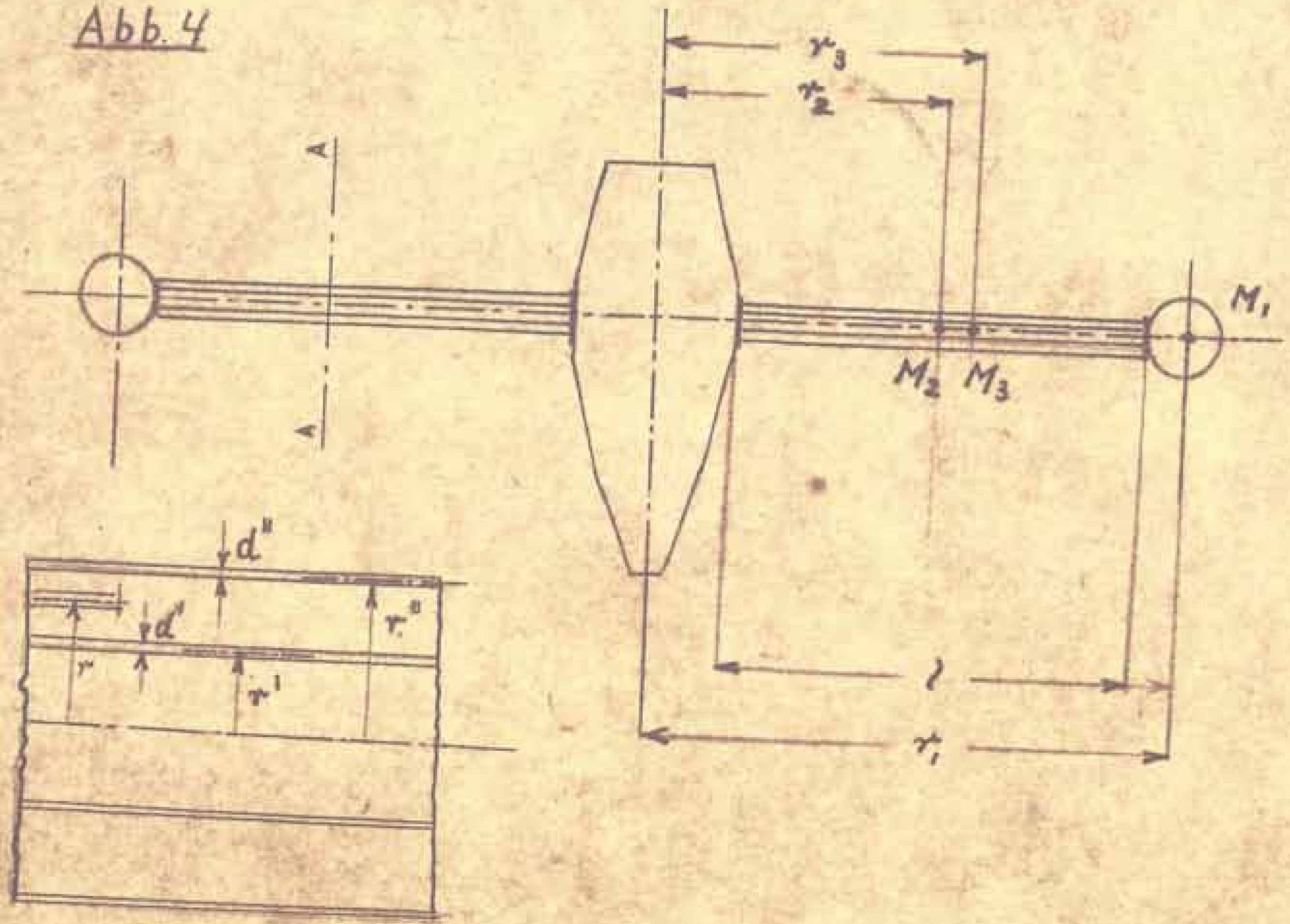
Abb. 4



SCHNITT A-A

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