History of Rocketry and Astronautics

Proceedings of the Thirty-First History Symposium of the International Academy of Astronautics

Turin, Italy, 1997

Donald C. Elder and George S. James
Volume Editors

Donald C. Elder, Series Editor

AAS History Series, Volume 26

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 17

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 2005

ISSN 0730-3564

ISBN 0-87703-518-0 (Hard Cover)
ISBN 0-87703-519-9 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198
Web Site: http://www.univelt.com

Printed and Bound in the U.S.A.

Chapter 3

Wernher von Braun's Doctoral Thesis: A Scientific Basis for the Type 'A' Rocket (Aggregate) Program*

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Background

Wernher von Braun (b. March 23, 1912; d. June 16, 1977), was born into the family of Baron Magnus von Braun, which in the Spring of 1920 moved out of Berlin. At school, the young Wernher built and tested in Tiergarten's alleys, a toy vehicle having mini-rockets! Also, when he was studying at 'Hermann Leitz' High School, at Spikeroog (1926), Wernher observed the Moon and the satellites of Mars,[3] using an astronomical field glass, given by his mother as a gift. As a student at the Technische Hochschule in Scharlottenburg-Berlin, he studied Prof. Hermann Oberth's book entitled *Die Rakete zu den Planetenräumen*, (The Rocket in Interplanetary Space) and participated in rocket launches at the Reinickendorf Center, as a member of The League for Interstellar Navigation. He also worked on the preparations for the memorable Rocket Conference on April 11, 1930, at the Central Post Office Amphitheatre of Berlin. When General Professor Carl Becker visited—in 1930—Reinickendorf with Captain Walter Dornberger, he commented on the knowledge of the student von Braun and also about his energy;[6] Prof. Becker advised young

* Presented at the Thirty-first History Symposium of the International Academy of Astronautics, Turin, Italy, 1997.

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Wernher to study Physics at the University in Berlin and to prepare his Doctorate under Professor Schuhmann of the Faculty of Sciences.

Since the subject of his dissertation would deal with Liquid Rockets, Wernher v. Braun's tests would take place at the Versuchestelle Kummersdorf—West Rocket Center! On October 1st, 1932, von Braun began his activity as an Associate Researcher at Kummersdorf, in the Liquid Rocket manufacturing Department, headed by eng. Walter Dornberger; also, on December 21st, 1932, he used the first Static Test Rig for Liquid Rockets in Germany. After an explosion, the Test Program for the Aggregate I Rocket was rescheduled (with Walter Riedel[3,8]).

The young Wernher worked hard, day and night, preparing his doctorate and also the static tests of the A-1 (Aggregate I) variants. After these A-1 static tests were 'OK', the first two new and startable rockets (named Aggregate II) were installed, in the winter of 1934, on Borkum Isle, in the North Sea. Nicknamed Max and Moritz, these two Aggregate II prototypes were successfully launched, and both of them reached 2,200 m in altitude;[4] this event, for Wernher von Braun, was comparable only to the successful presentation of his Doctoral Thesis.[6] For reasons of secrecy, the publicly announced title of the Doctoral Thesis was 'Über Brennversuche' (On Combustion Chamber Research).

Significant Scientific Aspects

Wernher von Braun's Doctoral Thesis entitled[3] 'Theoretic and Experimental Contribution to the Liquid Rocket Problem,' defended before The Faculty of Sciences Council (1934), included six sections (A-F), 19 graphs, 19 photographs, 14 numerical exercises and 87 mathematical expressions; the bibliography he included was new and at the highest scientific level.

In the Foreword he identified a lot of the liquid rocket engine's main characteristics, such as: the burning adjustment; the flexible adaptation to the computed conditions; rocket range amplification; the fuel tanks recharging repeatability; complications involving the structure of the rocket; the requirements for tank pressurization; danger amplification; the attitude control and stability necessary for a proper trajectory; and the extension of the combustion period to the detriment of initial acceleration.

The scope of the thesis, as the author himself declared, was to evaluate theoretical and experimental data for constructing a type 'A' rocket, nicknamed Aggregate I. For this rocket, the author built and tested a lot of combustion chamber variants, i.e. using alcohol and liquid oxygen to provide the fuel. These combustion chamber variants "...were systematically improved, exceeding the laboratory phase."[1]

A Lot of New Apparatus

As a skillful researcher, von Braun conceived, built, and brought up to standard some auxiliary devices which were necessary also for the test rig and for the rocket as a whole. Finally, these devices allowed the author to verify his theories, to validate adequate measuring methods, and to draw up "...the first burning tests with a fully assembled rocket which, at the present time (1934), was brought to the free air test phase."[1]

We can suggest that Section B, entitled 'Apparatus for Research and Evaluation,' will be useful to the readers: they will be able, as a result, to observe the importance of activities examined by the author, such as: the dynamometer system used for measuring thrust modification, utilizing digital values through an inserted electromagnetic device; the snapshot graphic view of fuel consumption, using an original dynamometer system; the measurement and registering of the pressure in the combustion chamber; the real time evaluation of the pressure values in the column and also at the end of the nozzle; and the calorimetric estimation of the heat loss, using the consumption of coolant water and its temperature (in the casing of the combustion chamber).

We can appreciate a lot of advanced ideas suggested by the author, dealing with the future of liquid rockets, such as: the timeliness of the new test rig having a measuring system for reactive forces and moments; the necessity of studying the role of the combustion chamber; the interdependence between the tilting and stabilizing moments; and the imperative of an efficient control system using a gyroscope or gas jets.

In his desire to help readers gain a better understanding of the organization of the test rig, the author added five photographs.

Greatest Importance: The Combustion Chamber

Section C of the Thesis, entitled 'Rocket Combustion Chamber Processes,' began with a paragraph dedicated to the 'Fundamental Relations,' including: total thrust; thrust increase introduced by a Laval Type nozzle; hypothetical and actual gas speeds; thermal efficiency; the coefficiency of losses; mechanical work; and full and optimal efficiencies. Using Hermann Oberth's arguments, the author defined the importance of ballistic efficiency for the energy demands of the launch, and he also traced an efficiency graph for a rocket's ballistic ascension.

Considering 'Burning and Expansion' as successive and independent processes, the author understood that the fuel chemical energy is adiabatically transferred to the gas carried out to a 'suppositional maximum temperature.'[1] This temperature, analytically calculated by him, was used for the calculus regarding the gas expansion. There were also calculated practical expressions for the real speed and temperature of the exhaust exiting from the nozzle section. The author's understanding of the exhaust of unburned alcohol vapors appeared to be realistic.

In the paragraph entitled 'The Thermodynamic Laws of the Reacting Process,' von Braun established the necessary measures to create and maintain in the combustion chamber the conditions necessary for energy to be transferred. It clarified the interface between gas flow, nozzle sections, and pressure gradients.

Using the critical parameters in the nozzle column, the author established for various proportions of fuel components, the following: (a) the column section dependence on the gas flow, for a certain combustion chamber pressure; (b) the dependence of the value of this pressure on the gas flow in the nozzle column; and (c) the maximum possible reactive force, depending on the combustion chamber pressure and, respectively, on the nozzle column section.

Von Braun analyzed the nozzle contribution for thrust gain, and there were a number of correct assertions, such as:

(i) if, in the ascending phase, high altitudes were reached, the nozzle's presence doesn't assure a significant gain in thrust, because of the nozzle's incapacity to adapt its geometry to the new conditions;

(ii) In the ascending phase, after a certain velocity was reached, the thrust value which is necessary for the launch can be reduced to prolong the combustion process. The author suggested a practical method for thrust diminution without a comparable reduction of the gas velocity;

(iii) The author used some empirical data dedicated to the calculus of the length and also for the profile of the reactive nozzle.

However, he understood the importance of gas flow friction.

In 'Section C' the fourth paragraph is entitled 'Equilibrium and Gases Dissociation.' In it the author defined such notions as: the weight ratio between alcohol and oxygen; the possible relations for chemical equilibrium involving the burning phenomenon in an engine; and an evaluation of the rocket engine running under different fuel conditions. This last analysis admitted that oxygen was sufficient only for burning H_2 and for partial oxidation of C (obtaining CO); consequently, the weight ratio was $\in$ (.64-.96) and the burning products (H_2O, CO_2, CO) were interacting, until Equilibrium, represented by the eq.: $CO + H_2O \leftrightarrow O_2 + H_2$ would be obtained! We appreciate the author's demonstration that Equilibrium's relation depends only on the temperature. It was demonstrated by the author that the Equilibrium Relation—as having a slow influence on the gas exhaust velocity—is dependent only on the temperature and not on the pressure.

By understanding the significance of the dissociation process, the author learned that the Equilibrium parameters' influence on the development of the degree of dissociation, also in what manner the Gas Constant is influenced by such a phenomenon.

The author allowed for the negligence in practice of the dissociation and of the Equilibrium relations; he also recognized their importance for the final burning products composition specification. Finally, he applied the Rule according to which the Equilibrium reaction rate is always the Resultant Velocity for both senses of the Reaction.

In the last paragraph of 'Section C' the author understood 'The Real Burning Gas Flow Evaluation' as being a polytropic process, having the exponent *n* influenced by such real phenomena as: the secondary burning in the expanding process; the friction, the dissociation and, especially, the super positioning degree of dissociation and burning processes; this last fact being a conditioning factor for the combustion chamber dimensions. Thus, by admitting expansion was a polytropic process, the author reconstructed the main parameters expressions for the gas stream and introduced the notion of 'an energy distributive coefficient,' a parameter depending on the *n* exponent and with which he elaborated the following burning gases flow Axiom:
The Gas Enthalpy before the beginning of the motion +
The Heat provided by the secondary burning (in the flow) =
The Total Energy (Heat + Mechanical Work) in the Exhaust section of the Engine

Using theoretic relations and some numeric values computed by measurements taken on the stand, the author obtained a lot of parameters for the real burning in the Aggregate I as follows:

- Polytropic expansion Temperature—912 K
- Equiv. of the Heat consumption for the flow initiation (electric units)—247 WE
- Equivalent of the Total Energy in the exhaust section—368 WE
- Exhaust velocity—1,180 m/s
- Critical velocity (in the nozzle column)—572 m/s
- Pressure measured in the combustion chamber—7.8 ata
- Pressure computed in the combustion chamber—7.7 ata

In the last paragraph of 'Section C,' entitled 'The Pulverization Problem,' the difficulties introduced by the previous gasification of the fuel components and also by the pulverization of the fuel (fully different from Diesel engines!), were performed using the previous experience at Reinickendorf Center: von Braun imagined and applied a lot of principles for efficiency and prevention against the danger of explosion. For instance, the theoretical and experimental study of the dynamics of fuel drops oriented the author to the following conclusions on pulverization:

- He defined the influence on the injection velocity of the pressure gradient between the fuel tank and the combustion chamber;

- He analyzed the gas flow in the combustion chamber (having the velocity of app. 25 m/s for the Aggregate I);
- He appreciated—in the fuel pulverization process—the drop diameter as having a significant influence on the vaporization period;
- He installed the fuel injectors at the top end of the combustion chamber;
- He established that total gasified fuel burning could begin only after its mixing with oxygen; this mixture has a big value for the relative velocity between the fuel drops and the flow in the combustion chamber.

Normal Run of the Aggregate I

In 'Section D' of the Thesis, entitled 'Technical Normal Run of the Aggregate I Rockets,' the author insisted on: (a) the perfecting of the combustion chamber variants for the Aggregate I rocket; and (b) the methods for testing them.

In the first paragraph ('The Rocket Combustion Chamber Run'), some details on how the construction and performances of the 1W, 1B, 2B, 2W variants were carried out; in all these cases, the author performed technical requirements as follows:

- The positioning of the entrance of the oxidizer region;
- The dimensions and raw materials;
- The pressure in the combustion chamber reduction motivation;
- The choice for a certain combustion chamber structure a.s.o.

Underlining that serial manufacture was a main condition for the military purposes of the Liquid Rocket, von Braun applied adequate technology: he changed the molding with the pre-forging and machining of the combustion chamber! For the same reason, he used a protective technology: the Eloxation (ELOXAL - Korund).

Von Braun described the necessity of using for such a process the continuous current and demonstrated the practical importance of the radial and/or tilted position of fuel injectors for the uniformity of combustion.

The performances of the Number 28 variant of the combustion chamber for the Aggregate I rocket are as follows:

- Effective Thrust—app. 39000 N
- Total fuel consumption—2 kg/s
- Combustion pressure—10.2 ata

- Combustion chamber dia—160 mm
- Nozzle col diameter—51 mm
- Divergent nozzle length—145 mm

Some photographs were dedicated to the Test Rig Panels and to the combustion chamber variants (1B, 2B, 1W, 2W) and their accessories.

In the second paragraph of 'Section D' entitled 'The development of a fully-automatic operation,' the author described a lot of original and efficient devices; all of them will be discussed at the end of this paper.

The theoretical aspects of maintaining constant pressure in the fuel components tanks were discussed in the 3rd paragraph of 'Section D;' it was entitled 'Theory of the pressure propagation problem.' The author obtained a practical rule for flying rockets having a system for fuel tanks pressurized with nitrogen: its capacity and, consequently, its weight, can be reduced if it will be able to pressurize more LOX than is necessary (the surplus will be exhausted before ignition).

The use of liquid nitrogen will impose a vaporizer and worsen the heat transfer (the Leidenfrost Effect), the author mentioned. We should mention the author's contributions:

1. He mentioned that any delay of the ignition will produce dangerous increases of the pressure;
2. He suggested also the pressure acted as a controller for an automatic ignition!

In the last paragraph of 'Section D,' entitled 'The Aggregate Rocket Assembly Run,' it described the following parts of the Aggregate I Rocket as experimental: a combustion chamber with a nozzle; systems for fuel component maintenance and operation; a nitrogen supplementary pressure system; an ignition system; and a gyroscope stabilizing system.

Until the end of the Thesis it was impossible for the author to comment about the improvement results for the Aggregate II rocket prototypes and also their future test launchings, which were to be successfully carried out in the Winter of 1934!

A Comment on Measuring Methods

In 'Section E' of the Thesis, entitled 'Measuring Methods—Results and Comments,' with the character of application included three paragraphs dedicated to the main parameters of a rocket engine: thrust, pressure and temperature.

In the 1st paragraph entitled 'Combustion Chamber Thrust Measuring,' the author underlined the importance of measurements made on the rig in comparison with those computed by the expressions including results on the beginning of the relationship between the flow velocity and the mixture ratio of the fuel components. For obtaining the conditions of a real burning process the author wrote the second paragraph of 'Section E,' entitled 'Measuring of the Combustion Chamber Pressure.' It described the combustion chamber sections, nozzle column and exhaust sections, having some pressure probes; it also mentioned the improving accuracy method and how to compensate for errors.

Specific to rockets, the intensive heat flows complicated temperature measuring methods in combustion chambers and nozzles; this was the subject of the 'Temperature measurement' paragraph. First of all, the author demonstrated the inability of thermoelectric measurements to function in very hot gas streams, even in the situation of the thermocouples being ceramically insulated! After this, he showed the methodology for temperature measurement in the combustion chamber and in the exhaust section, using a Wanner total radiative Pyrometer, having a spectral aperture.

As a serious researcher, von Braun added a lot of absorbing spectrometry measurements, to compare with the previous temperature values measured in the nozzle exhaust section.

The Ballistics of Ascending Rockets

The last section of the Thesis, 'Section F,' was entitled 'On Rocket Flight Ballistics.' It contained two paragraphs, both of them having a theoretical character but with numerical exercises and dedicated to the author's preoccupations with the future Aggregate II Rocket.

In the 1st paragraph entitled 'The Flight Stability Problem,' it insisted on some improvements to be applicable for the Aggregate II variant, a lot of them having to do with assuring the tilted launch. Also for the future, the author proposed an 'active remote control' using a lot of suspended gyroscopes, able to activate the stabilization and control surfaces.

In the 2nd paragraph of 'Section F' entitled 'The Calculus of the Vertical Launching Trajectory,' the author admitted initially a constant value of the thrust; using this simplified supposition, he integrated the rocket movement Eq, which it represented for the active phase, by an Order II Ricatti differential equation.

The author numerically solved this equation for the case of an Aggregate II rocket vertical ascension; i.e., for a burning 16s period and a thrust of 3,400 N (at a launching start weight of 50 kg + 32 kg of fuel), the author calculated as follows: after 10s the rocket will reach an altitude of app. 1,460 m!

Wernher von Braun's Contributions

A. We outlined, first, the following significant theoretical contributions carried out by von Braun in his Doctoral Thesis:

1. He emphasized the nozzle contribution for the gain of thrust at launch;

2. He analyzed the significance of the equilibrium reactions and the dissociation for the burning calculation;

3. He analyzed the contribution of the measuring results for the combustion chamber dimensions;

4. He used the rig test measuring results to elaborate a calculation method for the burning process, appreciated as a polytropic one;

5. He elaborated on fuel pulverization research;

6. He perfected the precise measuring of the efficiency of the combustion chamber & temperature of the nozzle;

7. He carried out a method for the vertical launch ballistic Calculus of the Rocket in its active phase; he succeeded in digitally integrating the Ricatti differential Eq. for the Aggregate II vertical ascension, i.e., for 16s of burning and 3,400 N Thrust, the Rocket will reach app. 1,460 m;

8. He appreciated the error introduced for tilting launch conditions; also by introducing air density variation with altitude in his calculus of the final burning, he obtained a gas exhaust velocity of 450 meters per second at an altitude of app. 3,100 m. Keeping in mind that the two Aggregate II prototypes tested in the Winter of 1934 at Borkum Isle were more heavily weighted, the precision of von Braun's calculations was impressive.

B. We underlined, secondly, the author's useful method to accompany the theoretical content of the paragraphs with numerical exercises, using even values obtained from the rig; there were fourteen such numerical exercises, most of them dedicated to verifying the theoretical hypotheses.

C. Third, we underlined the following significant experimental contributions carried out by von Braun in his Doctoral Thesis:

1. He conceived and built a mobile registration device for thrust measurement;

2. He obtained the calorimetric values for heat loss, using a relationship between the water cooling consumption and the temperature in the combustion chamber thermoprotection;

3. He registered in real time a lot of parametric graphs;

4. He used a radiative pyrometric method to measure the gas temperature in the combustion chamber and at the nozzle exhausts, and also an absorbing spectrometry method to measure the same gas temperature in the nozzle;

5. He established the error coefficient values introduced on the test rig;

6. He imagined and built an automatic igniter with a system allowing the rapid and efficient admission of the LOX in the combustion chamber;

7. He improved upon and used some industrial automatic faucets;

8. He imagined and built an electric remote control for a 3-way faucet (under .5 s for the ignition: the validation came from the tests!);

9. He conceived and used a system for maintaining a constant pressure in the LOX tank, using nitrogen supplementary pressure controlled by an original differential reductive faucet built using an Elektron alloy;

10. He identified and commented on the full stabilization of an in-flight liquid rocket with a gyroscopic device, using a 3-phase induction generator.

General Conclusions

In the authors' opinion, the high scientific level of Wernher von Braun's Doctoral Thesis, its exceptional value for rocket science and also the use of the best German Army test rig at Kummersdorf, all allowed:

1. The success in obtaining, in July of 1934, of a diploma for a doctorate in Physics (see the last page);
2. The excellent launches in the winter of that same year, of two Aggregate II rockets (nicknamed Max and Moritz) from Borkum Isle, both of them reaching an altitude of 2,200 m!

Acknowledgment

The authors of the paper would like to express their entire gratitude to Dr. Frederick I. Ordway III, for his encouragement to begin this research. We want to express that we are thankful to our wives who helped us all through this period; also for our friends, Johnny Georgescu, Dumitru Pâslaru, Letitzia Cuciureanu, who contributed to our efforts.

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Wernher von Braun's Diploma for 'Doctor in Philosophy and Professor of Belle Arte' (up-to-date Doctor in Physics), granted to him by 'Frederic Wilhelm University' in Berlin, July 27, 1934.

Major General Walter R. Dornberger, left, showing telegram of congratulations on the first successful launch of a V-2 rocket, 3 October 1942 to Wernher von Braun, probably in the officer's mess in Peenemünde Rocket Development Center, Germany. Photo: Deutches Museum Photo 35 750, SS&E Acc. #985-00380.

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