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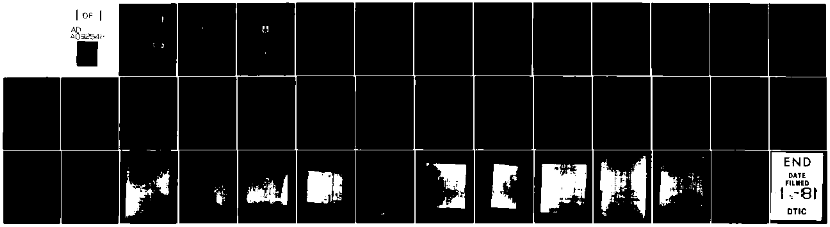

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FOREIGN TECHNOLOGY DIVISION

HYPERSONIC FLIGHT VEHICLE AND RAMJET ENGINE.
CONSIDERATIONS OF COORDINATION AND CONFIGURATION.

By

Ling Chi-Kuang

EDITED TRANSLATION

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HYPERSONIC FLIGHT VEHICLE AND RAMJET ENGINE. CONSIDERATIONS OF COORDINATION AND CONFIGURATION.

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HYPERSONIC FLIGHT VEHICLE AND RAMJET ENGINE. CONSIDERATIONS OF COORDINATION AND CONFIGURATION.

A Report By: Ling Chi-Kuang
Directed and Reviewed by: Wu Chuan-Hua
(A summary, for discussion use only)

January, 1963
Mechanics Research Institute, China Academy of Science

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(Fig 1 is referred to Figure 5 in Introduction, Figure 3 is referred to Figs. 11 and 12 in Introduction.

1. Introduction

In the past few years, mankind has successfully launched various kinds of artificial earth-satellites, moon rockets and manned satellite space vehicles, all with powerful multistaged rockets, and thereby accelerated the pace toward space exploration and interstellar travel. Further research and realization in the field imply that there will be great increases in the number and frequency of launches and in the effective payload. In the current technical standard, the effective payload of the multistaged rockets used in launching orbit earth-satellites is only 0.5 to 2% of their initial weight, and this figure does not exceed 8% even for high-energy-fueled and nuclear rockets. For example, three-staged liquid fuel rockets are used in the U.S. Saturn C_1 project. [1] If the effective load is a 10-ton earth-satellite of 480 Km altitude, the initial ignition weight will be 545 tons with an effective load ratio of 1.84% and the thrust of the first stage rocket will be as large as 750 tons. The initial weight and rocket thrust will be even greater for heavier satellites and so are the technical difficulties associated with it. This would not be satisfactory just from economic considerations. An important step to take is therefore an exploration of various launching methods and various possible propulsion fuels with economy taken into consideration. To quote the British ten year space research program [2]: "... Ten years from now, one would have to consider not only the problem of launching heavier satellites but how to increase the effective load from 1 ton to 10 tons for the same initial weight. That is to say, we have to study the problems of more economic launches." Evidently, the solution of this crucial step will have profound effects on the progress and depth of research in our nation's space science and interstellar flights.

It seems that there are two approaches to the problems of more effective and more economic launches: the first approach is to improve, through research, the characteristics of the propulsion engine and to search for more effective propulsion devices and configurations. The second approach is to conduct research in the "recoverable" (or "reusable") launching device which returns to earth according to a predetermined trajectory after it finishes its own stage of flight.

Literature and reports showed that, in the past few years, the American Aviation Society and Rocket Society have conducted some research and analyses on "recoverable" carrier stages [3 -6]. Technical problems and economic values of recovery have been compared in detail. In particular, it was pointed out that there is a wide open future for developing combustible turbine jet carrier stage and ramjet engine carrier stage. Their advantages over a rocket carrier stage have also been pointed out. The possibility of using air-breathing engines as carrier stages has just now attracted great attention in many nations and is considered to be a noteworthy approach. The objective of this report is to make an overall comparison and analysis, based on current literature, of the effects and feasibility in using high-energy liquid-hydrogen-fueled hypersonic ramjet engines as the first and second stages of a satellite launcher.

2. Comparison of results in current literature

The idea of using the so-called "air-breathing" engines (referring to the combustion gas turbine engine and ramjet engine) as the propulsion power device for carrier vehicles was first proposed by Chinese scientist Chien Hsueh-Sen [2] in 194?. Subsequent exploration regarding feasibility and effects of using air-breathing engines has continued to draw attention to scientists in the world. In ordinary rockets, the weight of the fuel in the carrier stages constitutes about 80-90% of the total weight and all the fuel must be carried up from the ground. Suppose air-breathing engines can be used as the propulsion power device during the atmospheric flight, then the oxygen in the atmosphere can be fully used and one can therefore imagine a substantial improvement in the effective payload ratio. On the other hand, one can also imagine using winged carrier vehicles to make full use of the aerodynamic flight in the atmosphere and thereby to minimize the fuel consumption effectively. With improved effective payload ratio, the versatility and reliability of the carrier device will also be improved. In 1951, Robert[11] suggested using F-102 aircraft as the first stage of winged guided missile. In 1955, Professor Sandorff suggested in his report [12] that large supersonic aircraft such as B-52 can be used as the first stage in the launching of earth-satellites. Later, a number of authors and research institutes [12] - [18] have made concrete analyses regarding the launching orbit, and engine characteristics calculations of using hypersonic ramjet engine combined with turbine jet engine as the power for carrier stages and for long-range transportation. A. Ferri [13] has made calculations using dual-cycle combustion gas ramjet engine as the first stage power and found that the effective load ratio can reach 3-3.4% upon acceleration to M = 4-6. (for 4.5 ton satellite in 300 km orbit and hydrocarbon rocket fuel). C. W. Frick and T. Strand [10] found that, through their simplified analyses, an effective load of 8% can be reached at M=8 in a three-staged launching device where the first stage uses a combination of combustion gas engine and ramjet engine and the second stage uses ramjet engine. W. R. Woodis made detailed calculations for the effects of using ramjet winged carrier stages in vertical launching and found that the effective load ratio is greater than the all-rocket devices by 7.7-8.1%. In a recent report by R. J. Lane [39] of the British Bristol Company, it was pointed out that, when liquid-hydrogen-fueled combustion, gas turbine and ramjet engines are used as the first and second stages a ratio of 9% can be reached at M = 7 and 13% at M = 12. As high as 18% can be achieved with the realization of "air breathing" (taking oxygen from the air). These figures are rather attractive. However, since various authors have made different assumptions and based their calculations on different data, it is difficult to deduce a definition number. As a reference for our discussion, we have listed the major results in the literature, together with their starting data and assumptions, in Table 1. One feature common to all plans is that the third stage is a rocket. The first stage is always air-breathing engine except Molder and Wu assumed nuclear rocket (I_s = 600 sec). Clearly there are substantial variations in the final effective load ratio because there are different maximum extinction velocities in ramjet engines.

Figure 5 presented in the "Introduction" of this meeting has launching orbit curves, expressed as altitude-velocity relationship, used by various researchers. Starting from practical engineering conditions of engines and flight vehicles, the curves provide a practical and adaptable "flight corridor" formed from the aerodynamic heating limit, the strength limit, and aerodynamic life limit. In this "corridor", researchers have chosen orbits characterized by constant engine strength limit, by constant dynamic pressure head (Frick and Strand), etc. Lane's orbit is reported to be the best for minimizing the initial weight and takes into account the pressure increase under the wings.

The total weight W_o of a given carrier stage is made of four parts: the fuel weight W_f, the structure weight W_s, the engine weight W_e and the weight of the communication and control systems W_c. We therefore write $W_o = W_f + W_s + W_e + W_c$. A balanced consideration must be given to each area in achieving a better launching method. For reasons of clarity and convenience of comparison, we have checked the weight distribution in each launching plan and expressed the results graphically in Figure 2. The fuel consumption of the device is related to other properties of the engine such as impulse ratio and thrust coefficient. Although the orbits are different in different plans, we have taken the characteristics curves of various authors and presented them in composite figures in Figure 3 and Figure 4 (See Figures 11 and 12 in Introduction).

Based on the comparisons made above, we can categorize the major factors affecting the performance of a plan where an air-breathing engine is used as the launching power device and make the following discussions on each:

(1) characteristics of the ramjet engine: As is evident from Figure 3, authors have used widely different characteristics curves for the ramjet engine in the analyses of a launching scheme. These choices have a direct effect on the result of the launching and conclusions drawn from the analyses. Curve (Equib). is based on a detailed characteristics calculation of hydrogen-fueled ramjet engine for M = 3 to 7 where equilibrium flow is assumed to exist in the ejector. In the meantime, Olson's experimental results (quoted in Reference 25) have been used in arriving at the characteristics curve (frozen) for the partially frozen case. [Details see meeting report on "Calculations and Analysis of Thermodynamic Properties of Supersonic Ramjet Engine".] The % curve should be considered most realistic and analysis of a launching plan should be based on this curve. Curve (6) is the calculation result of Ferri. His calculated results are evidently too high and, as a result, the effective load ratio is still 7.7% when orbit speed is reached. In general, McLafferty's curve (20) is relatively close to the actual curve (frozen) for M = 3 to 7 and Lane's curve (11) is somewhat lower. Also, the curve of Probert and Lane (10) is too high for $M > 7$ or supersonic combustion because the authors did not fully consider all the losses in the combustion and the effects of real flow in this part of their calculation. When we correct this upper-lower limit with the experimental results of Olson, it can be seen that subsonic combustion is still favorable at $M > 7 \sim 8$. Therefore, in the M = 4 to 7 or 8 range, it seems feasible and advantageous to use subsonic combustion ramjet engines.

(2) Fuel: As compared to H_2 fuel, kerosene fuel encounters less technical difficulties. However, as one can see from Table 1 and Lane's calculation in Figure 5, the maximum effective load

ratio is between 3 and 4% when the fuel is entirely kerosene -- not any better as compared to rockets. If the rocket stage uses LOX/H_2 fuel, then the ratio will reach about 8% upon acceleration to M12. Liquid hydrogen fuel will generally increase the effective load ratio 2 to 3 times from that of ordinary fuel under most maximum velocities. The figures in Lane's proposal are somewhat higher mainly because other plans assumed hydrocarbon fuel for the first stage engine and fuel comsumption weight assumed to be 15% of the initial weight. From Figure 3B, one can see that under the same M number a hydrogen-fueled combustion gas jet engine has a much lower specific fuel consumption rate -- only one half of that in a hydrocarbon-fueled engine or 0.9 Kg/Kg/hr. A crude estimate shows that, when both the turbine engine and the ramjet engine use liquid hydrogen fuel, the fuel weight is approximately 2% of the initial weight upon acceleration to M12. For hydrocarbon fuel, it would be 45% or higher. The advantage of using high energy fuel is very evident. (It has been shown by Lane, and the calculations in Appendix II, that there are no difficulties in the storage tank and vehicle layout for 2% initial weight of hydrogen fuel.)

(3) Maximum velocity: Tables and figures have shown that the maximum velocity of a ramjet engine has a relatively large effect on the effective load. Frick and Strand have done a simplified analysis and the effective load ratio to maximum velocity relationship is shown in Figure 6. Actually, as Lane's analysis shows, the specific impulse of a ramjet engine has approached that of a liquid-oxygen liquid-hydrogen rocket before it accelerates to M12. After this, the effect of further increase in maximum velocity is not pronounced. Probert claims that the effects are approaching those of a rocket for M greater than 7, based on characteristics estimates approximating a real flow. It should be pointed out that Ferri's suggestion (Figure 3(6)) that one would have a specific impulse greater than that of any other plan when a ramjet first stage accelerates to M_{orbit} under supersonic combustion is based on relatively idealized conditions.

In order to obtain a better performance, one can see from current data (Figure 3) that subsonic combustion ramjet engine should be used for M = 3 to 7 and supersonic combustion ramjet engine should be used for M treater than 7. Thus, if the maximum velocity is raised above M = 7, two types of engines are required and the weight ratio of the engine is therefore increased. For this reason, the beneficial effects of raising the maximum velocity should be weighted against the disadvantages of increased engine weight ratio.

(4) Structure and Engine Weight: When ramjet engines are used in the carrier stages, the structure weight is far greater than that of rockets which have a structure weight ratio of about 10 to 12%. All the proposed plans listed in Table 1 took 20 to 25% as the structure weight percentage. This is necessary in winged aerodynamic flights. According to calculations performed in the Applied Physics Laboratory at John Hopkins University [48], the propellant cooling structure and weight will increase the total weight of the vehicle by about 6% when hydrocarbon fuels are used. Lane used the 18% figure because of a sensible choice of orbit (lower) and because of the use of pressure increase under the wings. The engine weight is directly related to the initial thrust-weight ratio of the carrier stage and the latter in turn has a direct influence on the fuel consumption rate and flight time. There exists an optimum relation between the fuel consumption and the engine weight of the vehicle (Figure 6). The F/W value used by the various plans is approximately 0.5.

Combustion gas jet engine, because of its structure characteristics, has a greater weight per unit thrust. As compared to a ramjet engine, the ratio is about 7 to 1 or 6 to 1. (Jamison proposal). Because of this fact, the combination option of combustion gas and ramjet engines is worth considering. Figure 7 shows the comparison of specific impulse curves, as estimated by Zipkin, of the combustion gas engine, ramjet engine and a combination of the two. Figure 8 shows the fuel consumption curve and a comparison of engine characteristics for the French "Hound dog II" airplane where a combination type of engine is used. It can be seen that the combination engine is favorable to an increased effective load from the considerations of fuel consumption and engine weight. Extending the velocity range of a combination engine to M = 6-7 is therefore a topic deserving some attention.

(5) Types of take-off and flight: The type of flight is related to the choice of orbit and there have not been comprehensive data and analysis on the optimum orbit in this regard. Zipkin has made a comparison for horizontal and vertical take-off and for winged and unwinged flights (Figure 9). He showed that the highest load ratio is obtained in a horizontally launched winged vehicle; 8% is reach for M_{max} = 4.5. In the same figure we have supplemented with data for a horizontally-launched winged rocket [19] for comparison.

(6) The stage problem: Analyses showed that staged carriers are favorable to an increased effective load ratio; however, each additional stage requires its own engine and winged carrying area. For long range hypersonic carrier aircraft, the fuel weight is 6% of the total weight and the fuel tank structure weight is also a fairly large percentage. In this case, the advantages of a staged design is well recognized. For high energy-fueled launching carrier where the fuel weight is 20% of the total weight, the advantages of a staged plan must be considered together with the increased complexity in control. Jamison proposed two-stage aircraft launch (M = 0-7) but the effective load is still less than 3% because of the duplication in wing load. Another idea is to launch a ramjet engine carrier device from a supersonic aircraft. In this case the initial weight is taken to be the launching weight on the aircraft and, according to Lane's calculation, the effective load ratio can be increased to 30% for an aircraft at M = 4. Since the ramjet engine requires M > 1.5 for ignition, this idea deserves further consideration. The question of staging actually has to do with

the range of working conditions of the engine. Analysis in Appendix II shows that staging under a single engine is favorable only when the fuel consumption has reached a certain level, in other words, each type of engine should have a velocity range where the characteristics are good, it is a passive practice to overcome the problems of narrow working range of the air breathing engine and the excessive weight by staging. A more effective approach would be conducting research on the structure and configuration of the engine and thereby extending its range of working condition.

(7) About the "oxygen extraction" proposal: The recent suggestion of "extract oxygen from air" should be suitable for carrier devices with a wide velocity range. In the M = 4 to 7 range of the air-breathing engine, the air is compressed and cooled by liquid hydrogen to separate into liquid oxygen and liquid nitrogen. The liquified oxygen is then fed into the empty oxidizing agent tank of the rocket and the initial weight is reduced. Analysis shows that the weight reduced by liquifying oxygen from the air not only compensates for the weight of the cooling device but also provides a satisfactory effective load ratio without extending the extinction speed of the ramjet engine to a large value such as M = 7.

From the above analysis of results and information found in the literature, one realizes that in order to design a better ramjet engine for satellite launching, the following should be done: take full advantage of winged aerodynamic flight, choose a flight orbit corresponding to the minimum initial weight, increase the maximum velocity of the engine, use high energy liquid hydrogen fuel, reduce the engine structural weight by using pressure increases under the wings, reduce the adjustment range of working conditions and increase the thrust per unit area.

3. Considerations of aircraft configuration (and coordination with the engine).

To further investigate the feasibility of using a ramjet engine as carrier propulsion power, we have made preliminary calculations, based on available data and the analysis presented above, for a flight vehicle accelerated to M = 7 and we investigated the aircraft configuration and coordination with the engine based on this special case.

(1) Determination of aircraft shape and wing shape

In choosing an external shape for a hypersonic aircraft on has to consider dynamic efficiency (L/D, C_L, C_f...), coordination of the body and the wings, layout of the engines, aerodynamic heating and recovery requirements. We have determined the preliminary shape based on the following considerations:

(i)* An increase in the front edge angle α has great effects on the wave resistance. For the same arc length, a maximum thickness located near the rear makes the angle α a minimum and the increase in lower surface resistance will be less than the decrease in the total resistance. Furthermore, a wedge-shaped wing has its advantages from strength and manufacturing technique viewpoints. We adopted the wedge shape.

(ii) There seem to exist two schools of thought on the wing shape and on the coordination between wing and body. The earlier conviction [19] seems to be that the lower surface of the wing should be as flat and straight as possible to reduce friction and the upper surface is convex to reduce the adverse effect of centripetal force on the lift. Eggers and Ferri [30, [34] made the suggestion that the body be placed under the wing so that the lift can be increased by the pressure field produced by the body. Experiments indicated that, using this practice, L/D can reach 6.5 at M = 5. The new supersonic passenger carrier produced by North Aviation of France is of this type.

*Translator note - Starting here, third paragraph on original page 9 (marked), the copy has a number of illegibles. What follows is the best effort rendition.

(iii) From the consideration of pressure increase under the wing, the wing should have a certain arc length, that is, it should have an arc span ratio suitable for mounting an engine in the pressure field after the shock wave. [Too large or too small a ratio will not be suitable].

(iv) Generally after (illegible) supersonic and hypersonic aircraft (illegible) wing due to the great aerodynamic effect, lessens aerodynamic heating and improves (illegible) stability. In order to make use of the pressure under the wing (starting at M = 3) the sweepback angle selected is 70° (at M = 3 the Mach cone is 19.5° comparable to a 105° sweepback angle and consequently is (illegible) supersonic speed.

(vi) Since the aircraft accelerates from M = 0 to M = 7, we have to make sure that the vehicle has good characteristics in the subsonic range also. The analysis of Hans Malthopp indicates that the front edge should generally be made into a rounded head so that C_L is improved in the subsonic range (i.e. flow separation will not occur) and the situation of aerodynamic heating is also improved. It should be pointed out, however, that Malthopp's analysis was made for M = 10 or higher. Based on NACA test results, Hilton [37] pointed out that a sharp front edge does not have very much effect on $C_{L\ max}$ in the subsonic range (e.g., $C_{L\ super} = 1.0$, $C_{L\ sub.} = 0.7$, a loss of 0.3). A suitably designed front edge for supersonic flight will not suffer too much loss in the subsonic range. Based on the considerations enumerated above, we have settled on two designs for the aircraft external shape. One is a Δ wing where pressure increase is made use of and axially symmetric engine or dual engines can be mounted under the wing. The other design is based on the consideration of large effective lift surface (850 m^2). For the latter case, the "wing-carrying surface" of the body is increased and dual intake and exhaust are used. One example is the design of hypersonic transportation carrier suggested by Ferri [13].

(2) Considerations of the coordinated layout of the aircraft and the engine.

In the overall layout of a hypersonic aircraft, considerations must be given to dynamic efficiency, heating, as well as a sensibly located engine. With increased M number, the intake area of the engine increases and gradually becomes comparable to the wing's wind-facing area. (L. F. Nicholson [28] has made an area comparison). In addition, based on the analysis of #2, one can see that underwing pressure increase must be used to realize a better launching scheme. The feasibility, necessity, and associated problems will have to be considered in an overall plan. To this end, we have used the data in Appendix II and the discussion of Appendix I and assumed a 200-ton first-stage winged aircraft accelerating from M = 0 to M = 7. Using the results of thermodynamic calculations, variable working condition analysis and exterior shape consideration, we have made a preliminary plan* as shown in Figure 19 A, B, C and D. The major parameters of the first-stage vehicle design are listed in Table 1 below. In the process, we feel there are questions which should be further investigated and we also raised some requirements in the engine development.

Table 1 Major Parameters of Aircraft (for design assumptions)

Velocity (M)	Altitude (Km)	Engine	Fuel	Initial Weight (tons)	Initial	Initial thrust (tons)	Wing load (Kg/m^2)	Wing area (m^2)	Fuel Consumption
M0-3	0-24	Combustion turbine jet	Kerosene	200	0.42[1]	84	235	850	~15%
M3-7	24-36	Ramjet	liquid hydrogen	170	0.50[2]	85	200	850	

1 Based on IAS Preprint 859

2 Chosen based on a comparison of approximation calculations

(1) Wing area: For a 200-ton aircraft, if we assume W/S = 200 Kg/m^2 then the effective load-carrying wing area should be 850 m^2. If we use a Δdesign with a 70-degree angle, then the wing length needs to be 50 m and the maximum width approximately 30 m. The dimensions are

* This place does not permit (illegible) thetechemical aspects of aircraft structural design limited by performance and (illegible) properties.

indeed very large and they have direct bearings on the value of the structure ratio. Compared to the calculations made by G. J. Pietrangels [4] and Ferri (for hypersonic transportation carriers), the results are extremely close. But if one chooses a lower orbit such as the one suggested by Lane [39], then the W/S value can be chosen much larger and the calculated wing area can be reduced to 475 m^2. This would greatly reduce the structure ratio and should be considered in the choice of flight orbit.

(2) Varying thruster intake area. Thruster intake area greatly exceeds (illegible), affects a reasonable layout and at the same time frontal drag. But the intake area (usually equal to the wind-facing area) variation must satisfy a reasonable acceleration thrust of the vehicle and it is therefore directly related to the function characteristics of the engine. In Table 2 below, we have listed the maximum efficiency and the maximum thrust corresponding to the total intake area for M = 3 and for M = 7. Data are given for the two cases of with and without underwing pressure increases and results are based on the final calculated results of thermodynamic characteristics.

Table 2. Variation in intake area

		With Underwing pressure increase		No underwing pressure increase		
		Totally adjustable (Based on Olsen results & revised)		Totally adjustable (Based on Olsen results and revised)		Partially adjustable (plan IV* report)
		Maximum efficiency (complete)	Maximum thrust (complete)	Max. eff. (complete)	Max.Thrust (Complete)	Incomplete expansion
M = 3	Thrust per unit intake area (Kg/m^2)	3170	10600	1690	6210	1280 (k=4)
	Total intake area, A_2 (m^2)	268	8	50.2	13.65	66.5
M = 7	Total intake area, A_2 (m^2)	85.4	25.4	244	66.4	66.5

*** Report: Configuration Proposal and Characteristics under Variable Working Conditions of Ramjet Engine with Mach Number between 3 and 7.**

As can be seen, there is a very wide range in the intake area. When there is no underwing pressure increase, the variation is from a minimum of 13.6 m^2 to a maximum of 66.4 m^2 M = 7. There are some difficulties in the consideration of intake area and aircraft configuration layout, for instance, if one uses the maximum efficiency curve, the area reaches 244 m^2 at M = 7. When there is underwing pressure increase, the variation in intake area as computed from maximum thrust curve is smaller and the largest value is 25.4 m^2 (Figure 19B). The area for maximum efficiency is 85 · 4m^2 at M = 7. In order to realize pressure increase under the wing, it is estimated that, for every 1 meter of height, there should be at least 9 meters of distance from the front edge of the wing. The configuration of Figure 19B was calculated for shock wave situation. Considering the length of the engine, its maximum height cannot be greater than 4 meters. Under the maximum thrust curve, we have A'_I = 25.4m^2 for M = 7. This can be achieved by using a four-engine configuration with each engine having a width of 2 meters and a height of 3.2 meters. Although the variation in A_4 is very small under the maximum efficiency curve, the intake area poses some difficulties toward pressure increases under the wing.

The partial adjustment scheme is favorable in configuration design since it not only simplifies the adjustments but also reduces the range of variation of the exterior shape and area. According to Figure 16B of the Report "Configuration Proposal and Characteristic under Variable Working Conditions of Ramjet Engine with Mach Number between 3 and 7", engine adjustments can be carried out without changing its external diameter, but the total intake area still needs to be 66.5 m^2 because of the reduced thrust per unit area. We believe that the thrust per unit area can be increased by under-wing pressure increase and a reasonable match can be made between an axially symmetric partial adjustment engine and the aircraft, if the adjustment method is properly chosen. No further comparisons can be made on this point due to the lack of adequate information.

(3) The possibility of complete expansion: Generally speaking, the second and third stage rockets can be placed above the wing and the engine mounted under the wing. Thus, in the calculation of the total wind-facing area one must take into consideration the fact that rockets are riding on the back of the wings. A proper design where the combustion chamber and the tail exhaust ejector gradually bend upward will allow a greater degree of expansion. In an actual layout, we feel, there will be difficulties in realizing the kind of complete expansion one finds in thermodynamic calculations. For example, if one uses the dimensions of Figure 19A, an estimated maximum of about 8 meters, the height at the outlet will be 30 meters for complete expansion at M = 7. This is impractical. A more realistic figure is A4/A1 = 1.5 to 2. This estimate is of course based on the given configuration and serves only as a reference in estimating engine characteristics.

(4) Position of the engine: There is no doubt that when pressure increase is being used the engine should be in the back of the aircraft and centered under the wings. For this situation the the combustion gas turbine jet engines are on the two sides. As far as weight is concerned, the latter has more weight than the former.

(5) Configuration of the fuel tank: For the aircraft and vehicles we have discussed, the total fuel consumption at M = 7 is about 19-21% which converts to about 140-180 cubic meters. There is no problem in the design. Even for the hypersonic transportation aircraft which has a fuel consumption of 60%, design plans found in the literatures showed no particular problems.

Based on the overall design it can be seen that selection of engine operating characteristics (illegible) and control method should be considered as much as possible in combination with the aircraft's actual specifications. Properly selected flight (illegible) is an important aspect by effectively using pressurization, decreasing structural weight and varying engine dimensions.

5. About the "recovery" procedure

With the progressing research in space science and interstellar flights, the number of launches will greatly increase and the cost for launch will be a determining factor in the choice of plans. Since the initial investment and the cost of the engine and vehicle are relatively large in the ramjet carrier stage proposal, recovery and reuse must be considered in the competition with rockets. There is already an advantage in the recovery of the ramjet carrier stage because it is equipped with wings. Its economic superiority becomes more striking for a given number of launches when the effective payload ratio is increased. Based on available data, a number of authors have made estimates on this point, and we will not repeat in here. Figure 20 (taken from Reference 16) shows that for a maximum ramjet velocity of M 4.5 the cost of unit effective load is superior to that of multi-staged rocket. Even for a maximum velocity of M8, it is still more cost effective than the recoverable multistage rocket for relatively low launching frequency and it is also more reliable and maneuverable.

When recovery is taken into account in the actual design, one needs to include the weight of the take-off and landing control system and the added fuel weight for the return trip. It is estimated that these should be no more than 10% of the total weight, or, the effective load carrying ratio will be 0.5 to 1% lower than usual.

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(Figures which follow-totally unreadable)

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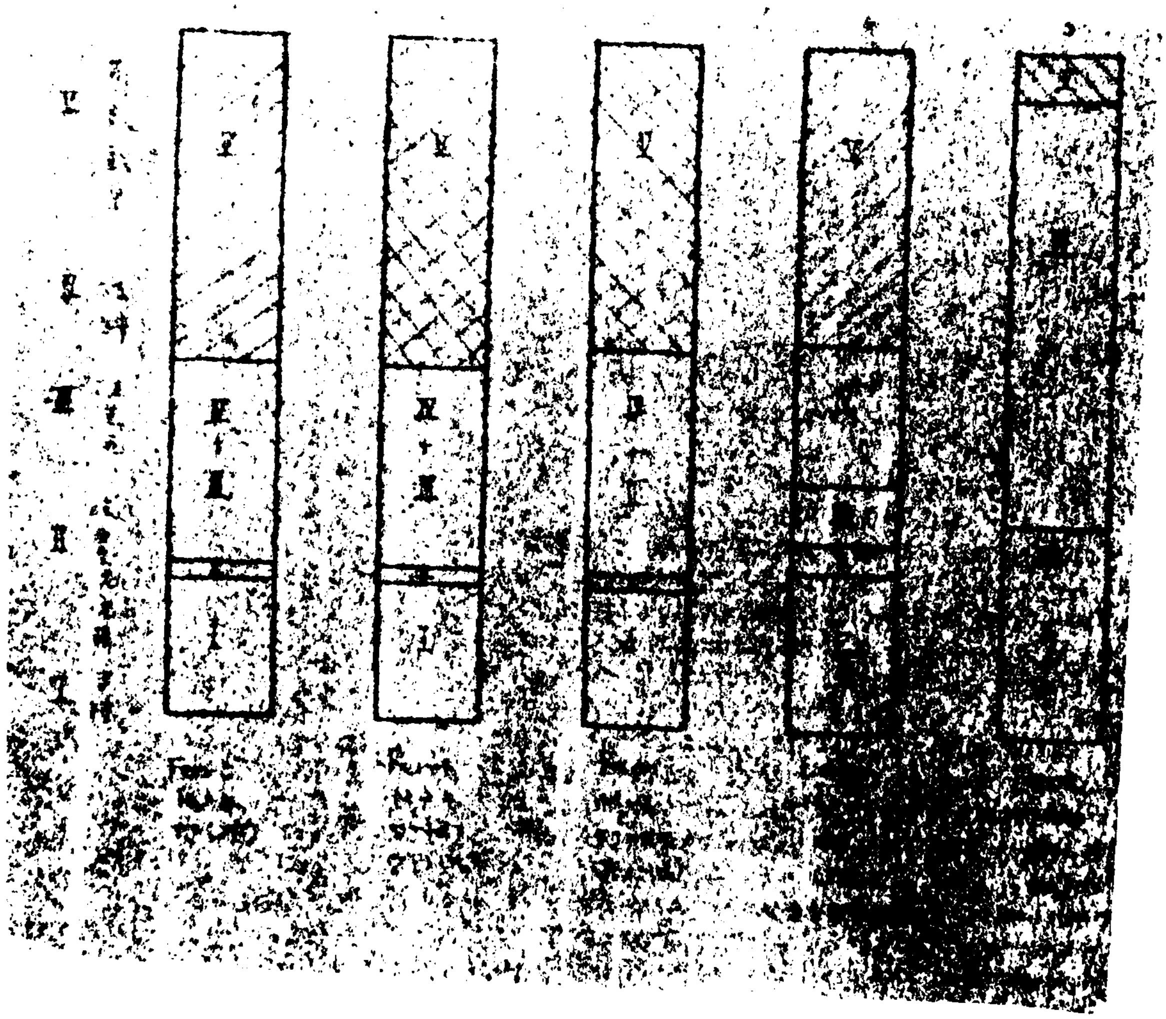

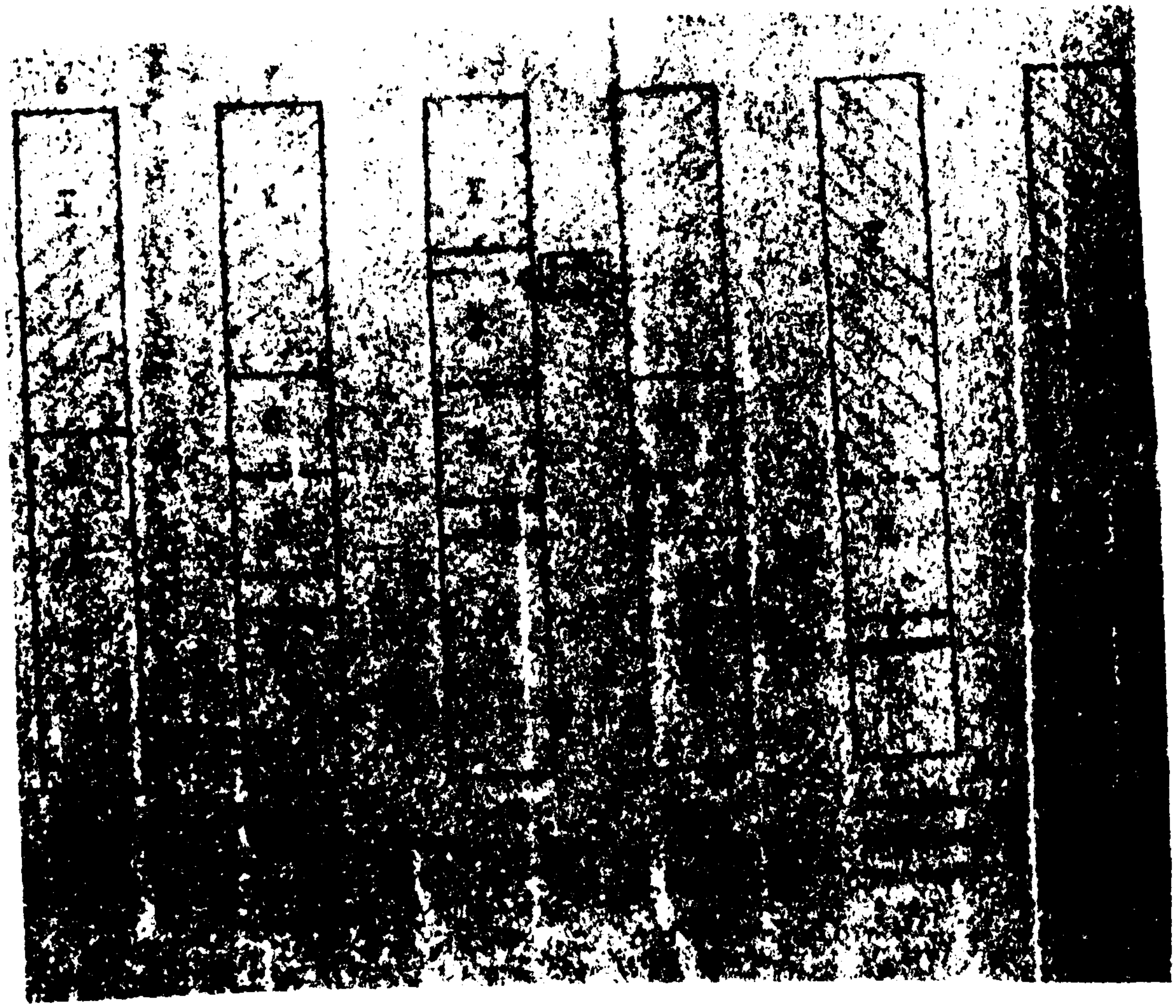

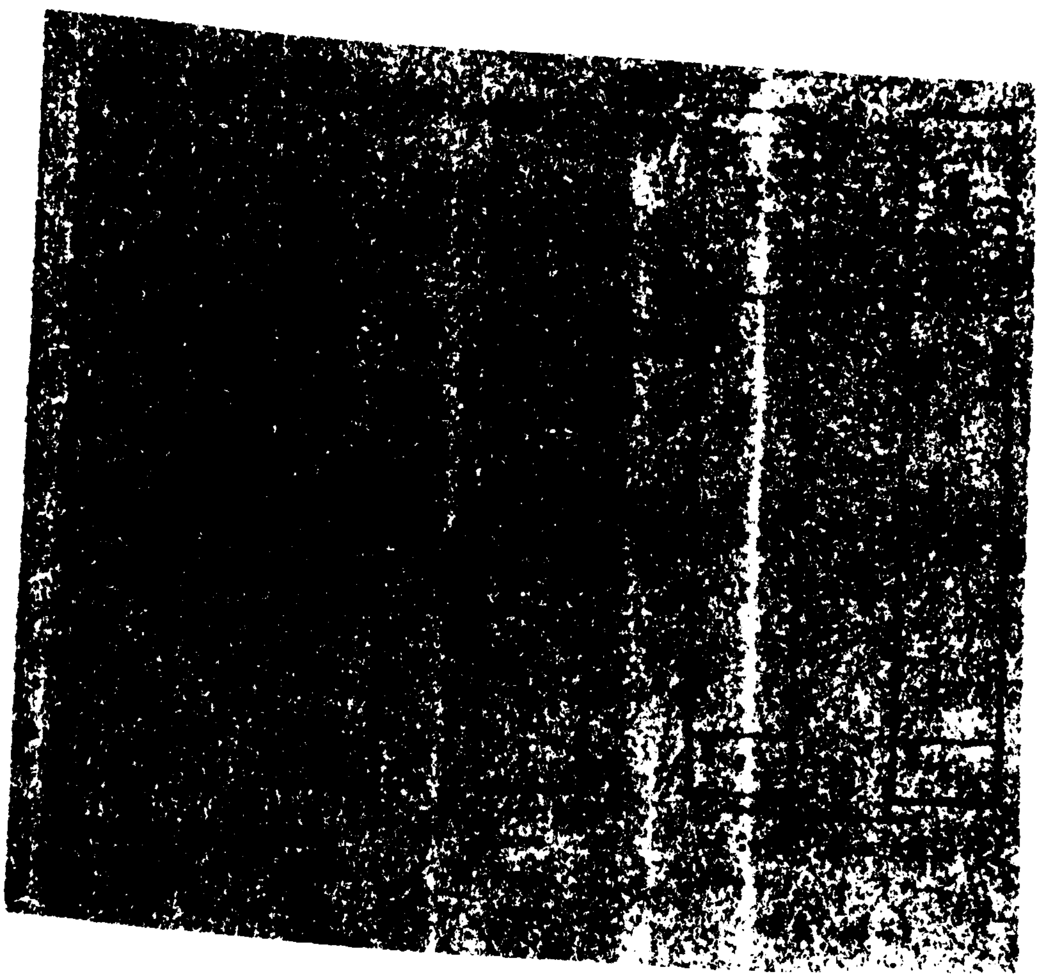

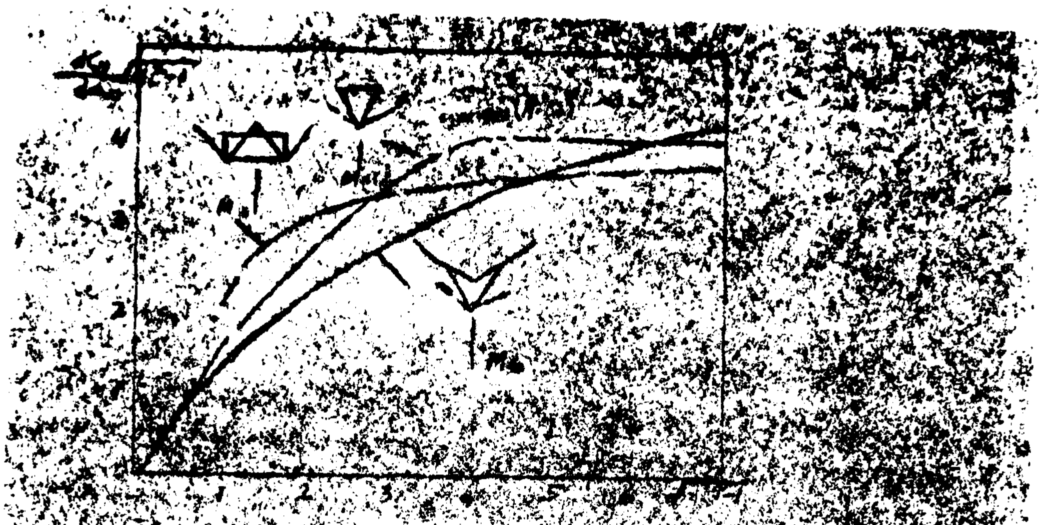

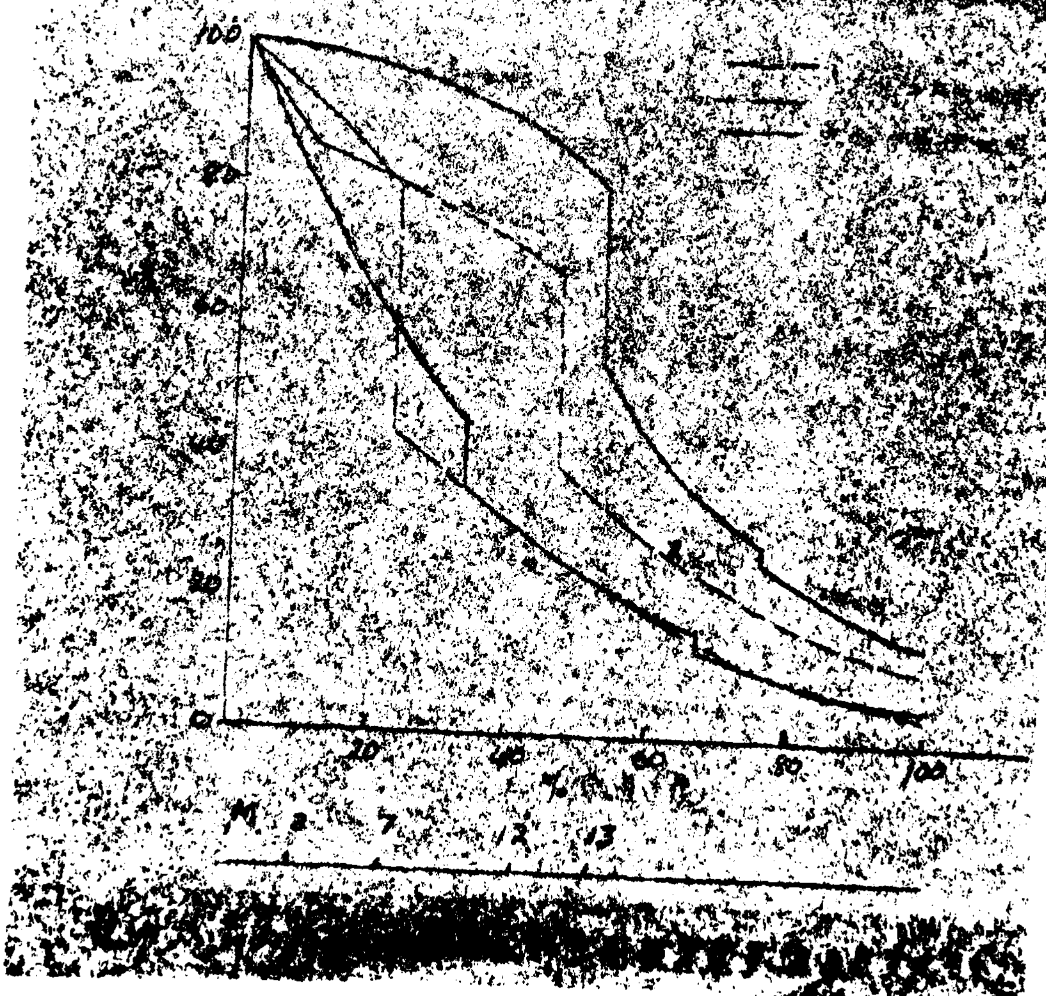

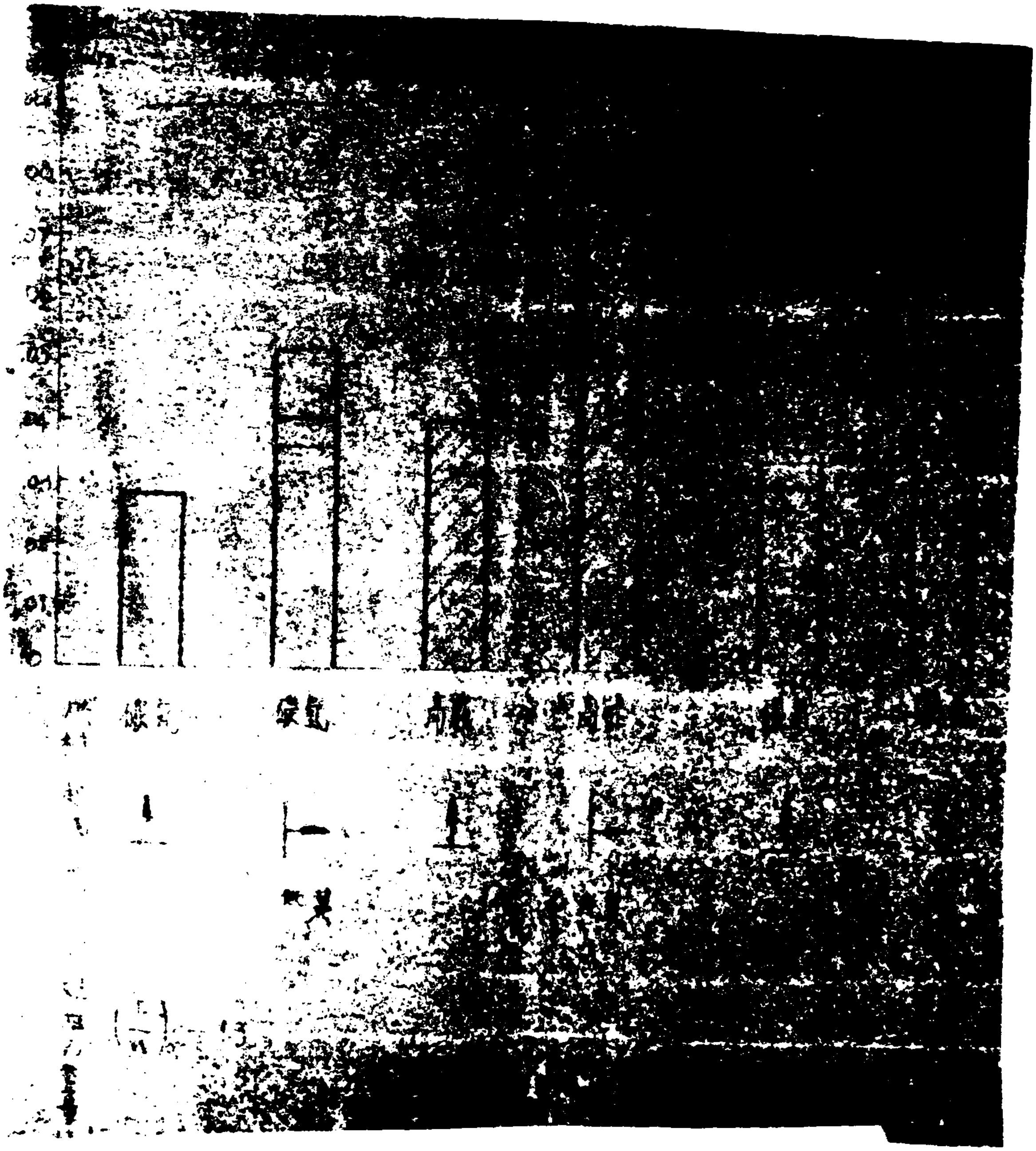

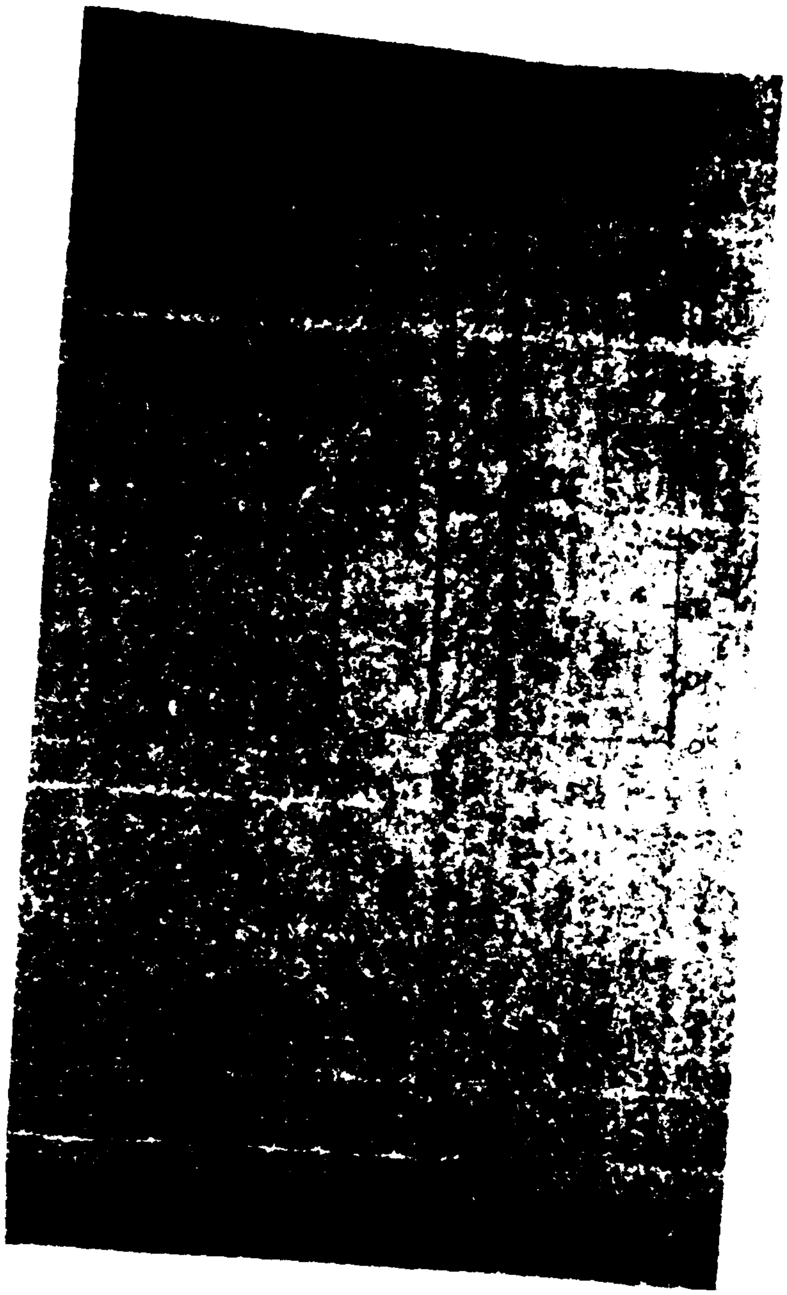

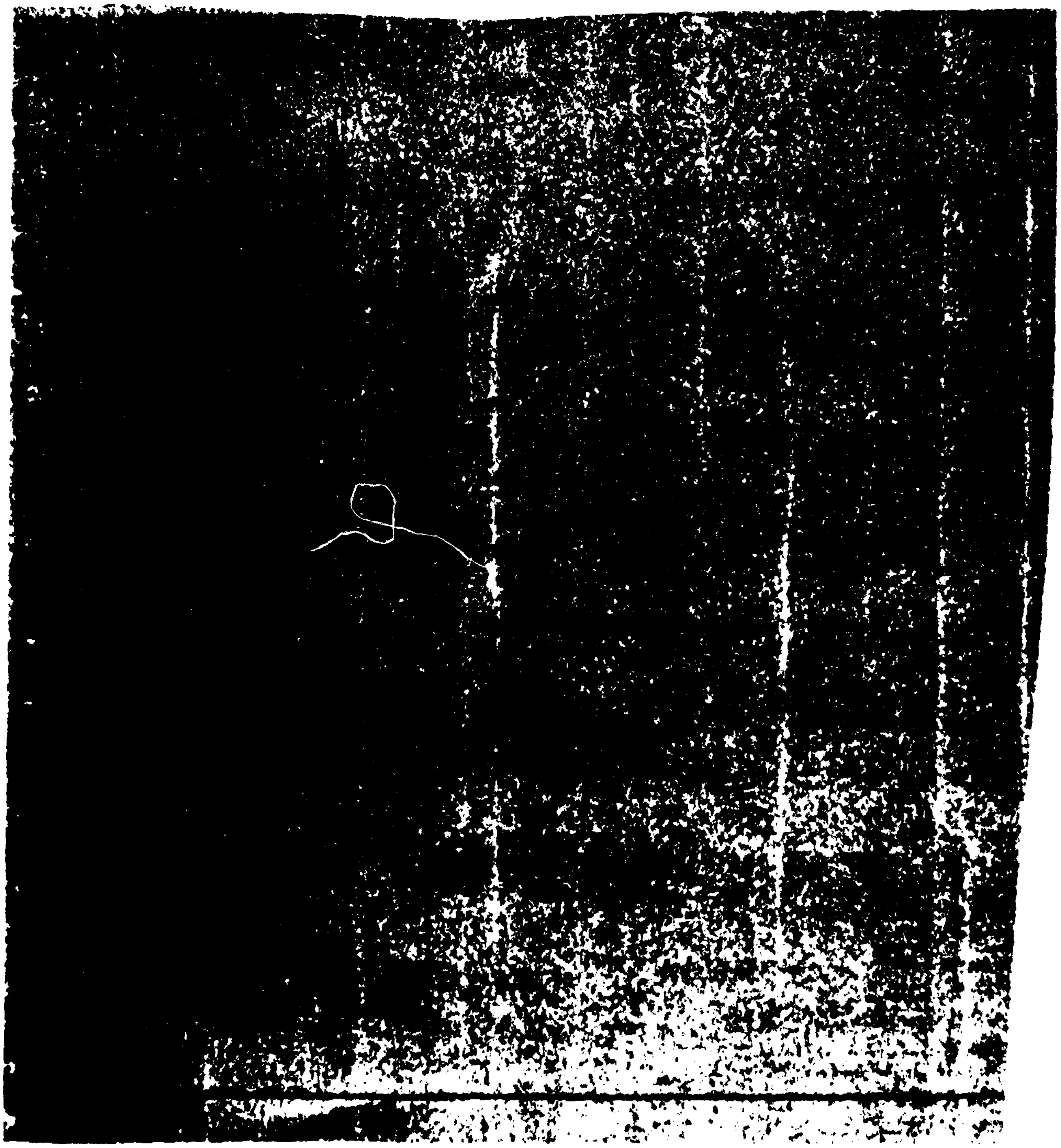

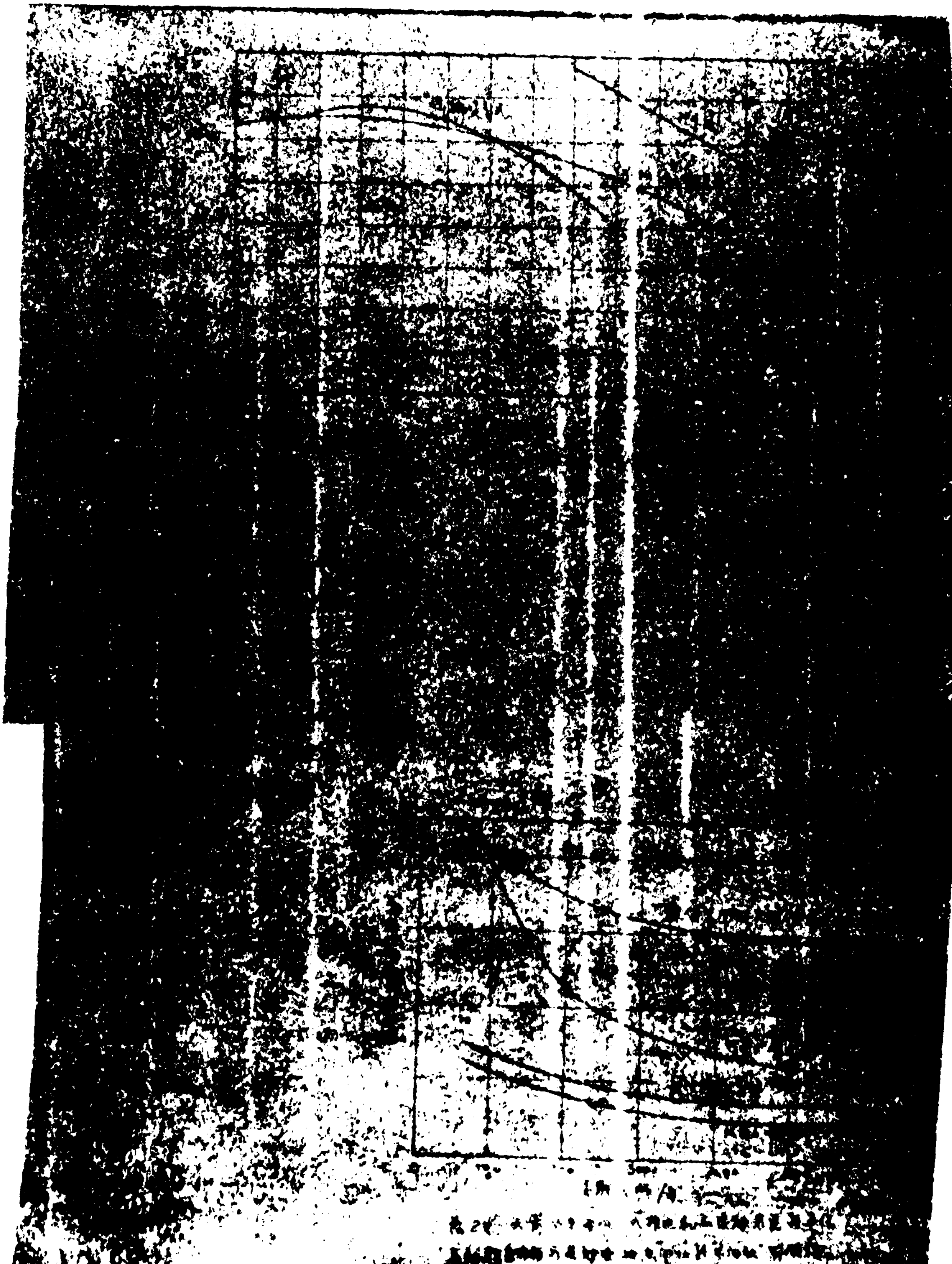

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