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OUTLINE FOR SPECIFICATIONS - S-40 ROCKET FACILITY

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The following information has been prepared as a guide to the design of the new rocket facility.

I. Research goals.

The objectives aimed for in the establishment of the new rocket facility in the S-40 area are:

(a) To do research on new, high energy propellant combinations which have been theoretically predicted to give high specific impulse values or have other desirable properties.

(b) To do research on problems still encountered with present propellant combinations, such as starting and combustion instabilities.

(c) To carry out above research on a sufficiently large size engine to minimize scale effects.

(d) To do research on simulated missiles or actual missiles and the problems associated with interaction of components.

The nature of some of the research projects will be:

(a) Demonstrating the attainment of high specific impulse theoretically predicted;

(b) Reliable starting and transition to steady burning;

(c) Injector, thrust chamber, and nozzle design;

(d) Cooling and heat transfer problems;

(e) Materials;

(f) Scale effects.

Specific impulse is one of the most important factors in rating various propellant combinations. Density is also an important factor, and its effect in establishing a relative rating of propellant combinations is dependent upon the specific mission. Availability is, of course, also an important consideration. A variety of investigators have found that for a given missile, the range is a unique function of impulse and density. A correlation of these investigations reveals that the range can usually be expressed as a function of Id^n parameter where $\underline{n}$ is an exponent that decreases from one to zero as the mass ratio (gross to empty wt) increases from one to infinity. Table I shows a listing of several propellant combinations in the order in which they have been rated for different possible applications (i.e. values of Id^n for various values of n).

As a result of analyses such as the above, the following propellants have been considered for study in the new facility:

Fuels - hydrogen, ammonia, and ammonia-hydrazine mixtures, gasoline, other hydrocarbons, and alcohol.

Oxidants - liquid oxygen, liquid ozone, mixtures of oxygen and ozone, liquid fluorine, and mixtures of oxygen and fluorine.

It is felt that the desired research goals can be attained by designing the facility for a running time of $1\frac{1}{2}$ minutes. Running times up to 3 minutes have been discussed, mainly because some present missile designs are for 3-minute operation. However, it was not considered desirable, from an economic standpoint, to design the present facility for this long an operating time. Not only the cost of the facility, but also the cost of running is very high for the longer running time. In this respect operation with liquid hydrogen merits some special consideration.

The low density of liquid hydrogen necessitates fuel propellant tank capacity about five times greater than is required for any of the other fuels to obtain an equivalent length of running time. Further, the extremely low temperature of liquid hydrogen requires special construction of the propellant tanks not required for any of the other fuels. Fuel tank capacities for the $1\frac{1}{2}$ minute running time have been based on fuels other than hydrogen.

Typical results of analyses of the effect of operating chamber pressure on rocket motor performance are shown in figure 1. On the basis of such curves, along with cost analyses, maximum operating chamber pressure for the new rocket facility has been set at 1200 psi.

II. Facility.

The facility will consist of the following major components:

A. Test stand.

B. Operations building - office, instrument, control, shop.

C. Propellant storage and handling.

D. Propellant vessels.

E. High pressure gas storage.

F. Hydrogen liquefaction equipment.

G. Ozone generation equipment.

A. Test stand.

The test stand shall be designed to accommodate rocket engines up to 100,000 lb. thrust, with actual mounting, plumbing, controls, instrumentation, etc. for 20,000 lb. thrust at the present time.

The engines will be mounted to fire vertically down and the stand will be constructed so that low pressure propellant tanks may be mounted above the engine to simulate vertical take-off of a missile. However, for most research activities propellants will be fed to the engine from tanks pressurized by gas and these are to be located in bays associated with the stand. A 5-ton crane shall be provided at the thrust stand for mounting purposes.

B. Operations Building.

The operations building shall consist of offices, an instrument room, a control room and a shop area.

(1) The office building shall be of sufficient size to accommodate about 32 people and include a conference room and drafting room. Building shall be designed so as to allow for expansion of office space in the future.

(2) The instrument area shall contain all instrumentation required for the facility and have space available for instrument service. The space required will be approximately 1600 sq. ft.

(3) The control room shall house the control console for the facility and a space of approximately 800 sq. ft. will be required.

(4) The shop shall contain equipment necessary for assembly and repair of engines, special tools and stock items. The space required is about 2400 ft^2. Overhead distance of about 15 ft. should be available and a traveling overhead crame of about 5-ton capacity provided.

C. Propellant storage and handling.

Storage areas and tankage shall be provided for the following materials. Storage factors are given as a multiple of the propellant tank capacity with additional allowance for handling and transfer losses.

(1) Liquid ammonia. Storage factor, 2. 2000 gal. tank, carbon steel, working pressure, 250 psi. Supplied by tank truck.

(2) Alcohol, hydrocarbons. Storage factor, 2. 3 tanks, carbon steel, about 1700 gal. each. Supplied by tank truck.

(3) Liquid fluorine. Storage factor, 0.85. (This quantity represents 1.4 times the amount of fluorine required for a 90 sec. run at maximum flow rate.)

1 - Transport trailer, 2400 liter

Delivered from Baton Rouge in 2400 liter capacity transport trailer.

(4) Liquid hydrogen. Storage factor, 2.5.

1 - Camco 2000-1 R.T.D. at Lewis Lab.		2000 l
3 - Camco 2000-1 R.T.D. from AEC		6000 l
2 - 750 l. dewars now at Boulder, Colo.		1500 l
	Total	9500 l

Gaseous hydrogen brought in by trailer units. Liquified on site.

(5) Liquid oxygen. Storage factor, 2.5.

2 - 1700 gal. tanks to be purchased = 3400 gal.

Delivered by tank truck requiring road suitable for 65,000 pound load.

(6) Liquid oxygen - ozone mixtures. Storage factor, 1.

1 - 750 l. dewar from Stearns-Roger Co.

Oxygen in storage. Ozone generated on site.

(7) Liquid nitrogen. Requirement based on (a) making high pressure nitrogen gas for pumping fuel , (b) cooling both propellant lines and tanks; (c) refrigeration of fluorine; (d) calibrations; (e) one day's requirement at maximum capacity for liquefaction of hydrogen.

1 - 3800 gal. tank to be purchased		3800 gal.
1 - 1700 gal. tank to be purchased		1700
3 - 2000 l R.T.D.'s from AEC		1600
	Total	7100 gal.

Delivered by tank truck.

D. Propellant vessels.

(1) Tank volume. The total tank volume for each propellant shall be sufficient to operate a 20,000 lb. thrust engine for $1\frac{1}{2}$ minutes. <u>Three</u> tanks shall be provided for each propellant. One tank shall have a volume of about 12 cu. ft. to allow operation of a 20,000 lb. engine for 10 seconds. Each of the other two tanks shall have a volume of about 49 cu. ft. each, giving a total volume of about 110 cu. ft. for each propellant.

(2) Tank location. The fuel and oxidant tanks shall be placed in separate bays which are partially open for ventilation. The fuel tanks to be on one side of the thrust stand, the oxidant tanks on the opposite side.

(3) Working pressure. The propellant tanks and all plumbing up to the motor shall be designed for a working pressure of 1500 psig.

(4) Materials. The propellant tanks and plumbing shall be of stainless steel type 347 or of monel for any parts that come in contact with the propellant liquid or its vapor.

E. High pressure gas storage.

(1) High pressure gas will be used for the transfer of propellants to the engine. Gaseous nitrogen will be used to pump alcohol, ammonia, and hydrocarbon fuels. High pressure helium gas will be used to pump oxidants. High pressure hydrogen gas will be used to pump liquid hydrogen.

(2) Capacity.

(a) Nitrogen. 986 cu. ft. water capacity. 149,000 std. cu. ft. Stored at 2400 psi. Approx. 40 cylinders, 12" diameter × 40 ft. long. High pressure nitrogen gas will be prepared from the liquid nitrogen supply by means of a commercial pump and evaporator unit. The pump and evaporator unit will produce gas at the rate of 5600 std. cu. ft. per hour.

(b) Helium. 905 cu. ft. water capacity. 137,000 std. cu. ft. stored at 2400 psi. Approximately 36 cylinders of 12" × 40' long. Helium gas will be brought in by our trailer from commercial supply in Texas, or New Jersey.

(c) Hydrogen. 1100 cu. ft. water capacity. 165,000 std. cu. ft. stored at 2400 psi. Approximately 44 cylinders of 12" × 40' long. Hydrogen gas will be brought by our trailers from commercial supply in Barberton, Ohio.

F. Hydrogen liquifaction equipment.

Liquid hydrogen will be produced on the site at the rate of about 60 liters per hour by the H. L. Johnston design trailer units obtained from the U. S. Air Force.

High pressure gaseous hydrogen will be trucked in by our own trailer units. Liquid nitrogen will be supplied to the site by the transportable 2000 l. R.T.D. units. An area of about 30,000 ft^2 is required to operate this equipment and store hydrogen. Equipment for which storage area must be provided consists of (a) 3 large transport trailers housing the liquefaction equipment; (b) 1 gas tube trailer~~s~~; (c) 6 transportable dewars for liquid hydrogen; (d) one transportable dewar for liquid nitrogen.

G. Ozone generation equipment.

III. Layout considerations.

Spacing of buildings and storage areas has been made in accordance with the Army Ordinance Safety Manual. The applicable distances will be mentioned under the specific items below.

Figure 8 is a plot reproduced from Robinson, "Explosions, their Anatomy and Destructiveness." On a plot of distance versus weight of explosive, it shows,

(1) The Ordinance Safety Manual Class 9-10 unbarricaded Inhabited Building Distance

(2) Limits of serious structural damage

(3) OSM Intraplant distance, and

(4) reported glass damage as a result of accidental explosions.

(a) Operations building. - Comprises offices, instrument center, control center and shop. Located to be safe from test area and hazardous storage areas. Is protected from test stand by natural earth barrier. Location 830' from test stand is safe inhabited building distance for barricaded storage of 7500 lbs. of explosive (1-1/2 minutes of running for a 20,000 lb. motor requires 7500 lbs. of propellant). Safe inhabited building distances are set up to prevent serious injury of personnel and major structural damage.

(b) Test stand and duct. - Arranged for vertical firing on plateau (el. 730), about 30 ft. below top grade level. Horizontal run of exhaust duct used for spray cooling to take advantage of liquid head, thus eliminating need for water pumps. Vertical rise of exhaust duct to be used for packing for further scrubbing of exhaust gases if necessary. Outlet of vertical stack to be above top grade level to aid dispersion of stack gases.

This location of test stand (a) provides natural earth protection between test stand and other areas; (b) requires minimum amount of excavation; (c) allows full use of water head for pumping; (d) is centered in wooded area and ravine for noise reduction advantage and maximum distance from private homes.

(c) Auxiliary control room instrument panel room and small shop area. - Located adjacent to test stand. Auxiliary control room to be used for cold flow testing and calibration work.

Instrument panel room - to mount switch panels for running lines to instrument room; to contain instruments for which long leads are not permissible; to contain possible signal amplifiers.

Small shop area - for housing safety equipment and tools necessary for operation of test stand.

(d) High pressure gas storage. - pressurized gas used to pump propellants into motor. Located close to propellant tanks to keep lines short and pressure drop low. Consists of manifolded cylinders mounted vertically on an incline to facilitate draining after hydraulic testing. Some fragmentation protection desirable - earth bank or metal shield.

(e) Water reservoir. - Contains water for exhaust gas and engine cooling and deluge of stand areas. (1) Located with outlet about 10' above normal top grade level to provide head for pumping; (2) located reasonably close to stand to keep water feed lines short as possible. Capacity 300,000 gal.

(f) Ozone storage. - Quantity considered is 1620 lbs. or 1 minute operation of 20,000 lb. engine. Considered as equivalent weight of TNT and located, area being barricaded,

600 ft. from inhabited bldg.,
180 ft. from highway,
225 ft. from intraline building (either test stand or the ozone preparation building).

area diked.

(g) Ozone generation plant. - Located 225' from ozone storage area and:

(a) 180' from inhabited bldg. allows accumulation of 200 lb.
(b) 350' from inhabited bldg. allows accumulation of -500 lb.

(h) Hydrogen liquifaction and storage equipment. - Storage is in transportable dewars. Class 950 in OSM. Storage of 900 lbs. requires 490' from inhabited building if the area is barricaded (980' if not), and 300' from a public highway. Located at least 200' from any oxidant storage. Terrain should be suitable for movements of the gas trailers and liquid dewars.

(i) Liquid fluorine storage. - Stored in transportable dewars which have liq N_2 jackets. Class 1050 in OSM. No recommended distances set up because of unknowns involved. At least 200' from an operations building. Need not be close to test stand because of transportable dewars. Must have overhead deluge tank of NaOH solution and limestone pit underneath for safety features. Area diked. Water safety shower on site.

(j) Liquid oxygen storage. - Permanent mounted tanks. Close enough to stand to permit transfer through pipes; accessible for heavy trucks; area diked; natural protection from stand desirable.

(k) Liquid N_2 storage. - Located same as liq O_2 storage. Some storage may be in transportable dewars to use at hydrogen liquifier, fluorine storage and ozone storage areas.

(l) High pressure liquid N_2 pump and evaporator. - For charging gas storage bottles. Close to liq N_2 tanks. Length of high pressure gas line not critical.

(m) Settling basin. - Large enough to receive all H_2O flow from exhaust duct. Neutralization by either of two methods. (1) Water-HF-lime slurry solution flows into this basin where most of solids settle out in a few hours. Supernatant liquid is pumped out, neutralized, run through filter, thence to sanitary sewer system. Solid sludge remaining in basin to be shoveled out into truck and hauled away to dumping spot when the accumulation in the basin so demands. (2) HF solution is neutralized with sodium hydroxide, yielding all soluble product. Solution is pumped into sanitary sewer.

(n) Nonhazardous fuel storage. - Ammonia, hydrocarbon, and alcohol. Location near main service road for easy filling access; natural protection from test area desirable, 200 ft. from oxidant storages. Transfer piping to stand. Area diked.

(o) Test observation post. - For direct observation of engine and stand area during firings. Contain telescopic viewer, communication with control center, and engine cut-off and safety system controls. Located for (1) direct view of engine, (2) about 200 feet from engine.

(p) Future expansion. - Future thrust stands may be located along the bank. Storage areas for liq oxygen, liq N_2 and fuels all capable of being added to, although hazardous compound storage (if added to) will probably then no longer conform to OSM tables.

(q) Roads. - Access roads for LOX, liquid nitrogen, and liquid hydrogen storages to take up to 65,000 lbs. gross wt; to test stand, lighter trucks.

(r) Lime-slurry or sodium hydroxide solution reservoir. - Slurry to be added to water-HF solution exiting from exhaust duct. Located (1) close to exhaust duct; (2) accessible for filling; (3) high enough so that head is available for pumping.

IV. Gas scrubbing and cooling.

The requirements for the duct into which the exhaust gases from the rocket are discharged are that the outlet HF concentration be reduced to a maximum of 100 ppm, and the gas be discharged into the atmosphere about 30 ft. above the ground level. This will yield a maximum HF concentration at ground level no more than about 1.0 ppm due to atmospheric diffusion. Allowable HF concentrations are listed as follows:

Maximum allowable for 8 hours daily exposure	3 ppm
Immediately irritating	25 ppm
Dangerous for short exposure	50 ppm

Mist must be eliminated from the exhaust exiting from the duct. In order to lower the exit gas velocity so that the gas may be scrubbed, the mist eliminated, and so that the noise generation will be low without going to an excessively large diameter duct, the gas temperature must be reduced to about 150° F. The exit diameter will be 20 feet.

The cooling and scrubbing requirements are outlined below. A more detailed analysis may be found in a memorandum on the subject by P. M. Ordin.

Propellants: Hydrogen-Fluorine and Ammonia-Fluorine.

The most stringent requirements are found in the hydrogen-fluorine system, so that a design which will satisfactorily cool and scrub this system will be sufficient for ammonia-fluorine combination also.

Thrust size. - 20,000 lbs.

Operating range. - (a) 5 wt. percent H_2 - maximum temperature
(b) 10 wt. percent H_2 - maximum performance
(c) 20 wt. percent H_2 - optimum regenerative cooling

The 5 wt. percent H_2 combination gives the maximum heat load for the cooling system to handle; the 20 wt. percent H_2 combination gives the maximum gas handling capacity requirement.

Assumptions. -

(1) Experimental specific impulse is 85 percent of theoretical
(2) Flow and performance values based on operating pressure of 300 psia
(3) Theoretical chamber temperature is attained

Calculations. -

(1) For 5 percent H_2 system (maximum temperature)
Specific impulse = 310
Total propellant flow = 64 lb/sec
Fluorine flow = 60.8 lb/sec = 1.6 lb mol/sec
Hydrogen flow = 3.2 lb/sec = 1.6 lb mol/sec
Chamber temperature = 4600° K = 8280° R
Average specific heat of exhaust products for 8280° R to 700° R = 0.73 Btu/(lb)(°R)
Heat of solution of HF in water = 415 Btu/lb of HF
Reaction: $1.6\ H_2 + 1.6\ F_2 \rightarrow 3.2\ HF$
Total heat load to cool to 150° F (Assuming HF is absorbed and no inert gas present to carry out uncondensed water vapor)

$$Q = \underbrace{(64)(0.73)(8280-710)}_{\text{sensible heat}} + \underbrace{64(415)}_{\text{heat of solution of HF}} = 380{,}600 \text{ Btu/sec}$$

Water requirement: assume water in at 80° F
assume water out at 140° F

$$\frac{380{,}600}{60} = 6350 \text{ lb/sec} \approx 45{,}700 \text{ gpm}$$

(2) For 20 percent H_2 system (maximum inert gas)
Specific impulse = 306
Total propellant flow = 65 lb/sec
Fluorine flow = 52 lb/sec = 1.37 lb mols
Hydrogen flow = 13 lb/sec = 6.5 lb mols
Chamber temperature = 2720° K = 4900° R
Av. Spec. heat = 1.001 Btu/(lb)(°R)
Reaction: $6.5\ H_2 + 1.37\ F_2 \rightarrow 2.74\ HF + 5.13\ H_2$

Total heat load to cool to 150° F:

$$Q = \underbrace{(65)(1.001)(4900-610)}_{\text{sensible heat}} - \underbrace{(0.388)(5.13)(980)}_{\text{heat of vaporization of } H_2O} + \underbrace{(2174)(20)(415)}_{\text{heat of solution of HF}}$$

$$= 300{,}750 \text{ Btu/sec}$$

Water requirement:

$$\underbrace{\frac{300{,}750}{140-80}}_{\text{water for sensible cooling}} + \underbrace{(0.388)(5.13)(18)}_{\text{water out as steam}} = 5010 + 36 = 5046 \text{ lb/sec}$$

$\approx$ 36,300 gmp

(3) Inert gas handling capacity of system.
Figure 2 shows the volume of gas handled for the systems $H_2 + F_2$; $NH_3 + F_2$; LOX + gasoline for a 20,000 lb. thrust motor.

V. Waste disposal.

The effluent water from the scrubbing duct will contain 1-1/2 to 3 per-cent HF solution. This solution will flow into a large basin and will be treated in either of two ways outlined below.

(1) The first method is to add lime slurry to the basin forming CaF_2 and water. Most of the CaF_2 will precipitate and settle out. The liquid will be filtered and the filtrate, containing ~~0.0016 percent CaF_2~~ (8.0 ppm of fluoride ion) pumped either to the sanitary sewer or into the river; pH = 9.5

(a) If excess $Ca(OH)_2$ ~~must~~ be added raising the pH above 10 to complete the reaction, this may be neutralized with oxalic acid, precipitating calcium oxalate. The liquid then will be filtered and the filtrate, containing 0.0016 percent CaF_2 and 0.00068 percent calcium oxolate pumped. to the sewer or river.

(2) The second method is to add sodium hydroxide solution to the basin forming NaF which is completely soluble. The concentration of NaF will be about 3.5 percent (about 15,000 ppm of fluoride ion). This will be a liquid requiring no filtering or further treatment if the fluoride concentration is acceptable for the sanitary sewer system.

The following values are taken from table 19 of the Water Quality Criteria by the State Water Polution Control Board, Sacramento, California, SWPCB Pub. No. 3, p. 256, 1952.

(a) Adults may safely drink 2 gallons per day of water containing 10 ppm of fluoride ion.

(b) 180 ppm of fluoride ion toxic to man in drinking water.

(c) 2000 ppm of fluoride ion is a lethal dose in drinking water.

The requirements for water which may be discharged into the Metropolitan Park water system are as follows. (Excerpts from Resolution No. 2762.)

1. Where provision is made for the disposal of industrial waste, no sanitary sewage shall empty into the industrial disposal waste.

2. Temperature of effluent as it enters the storm sewer, not to exceed 90° F.

3. Turbidity, not over 25 ppm.

4. Color, not over 50 ppm.

5. Dissolved oxygen, not less than 6.0 ppm.

6. Biochemical Oxygen Demand (5 day at 20° C) not over 10 ppm.

7. Coliform bacteria, not over 1000 per ml.

8. Suspended Organic Solids, not over 15 ppm.

9. Free acid, none.

10. pH, not less than 6.5 nor over 10.

11. Visible oil, none.

12. Ether soluble matter, not over 15 ppm.

13. No inflammables.

14. No bulk solids produced in solid or semisolid form.

15. No sludges or trash of any kind.

16. Upper limits of metals as follows:

Iron as Fe	5 ppm
Chromium as Cr(hexavalent)	3 ppm
Zinc as Zn	4 ppm
Copper as Cu	1-1/2 ppm

17. Cyanides, not over 15 ppm.

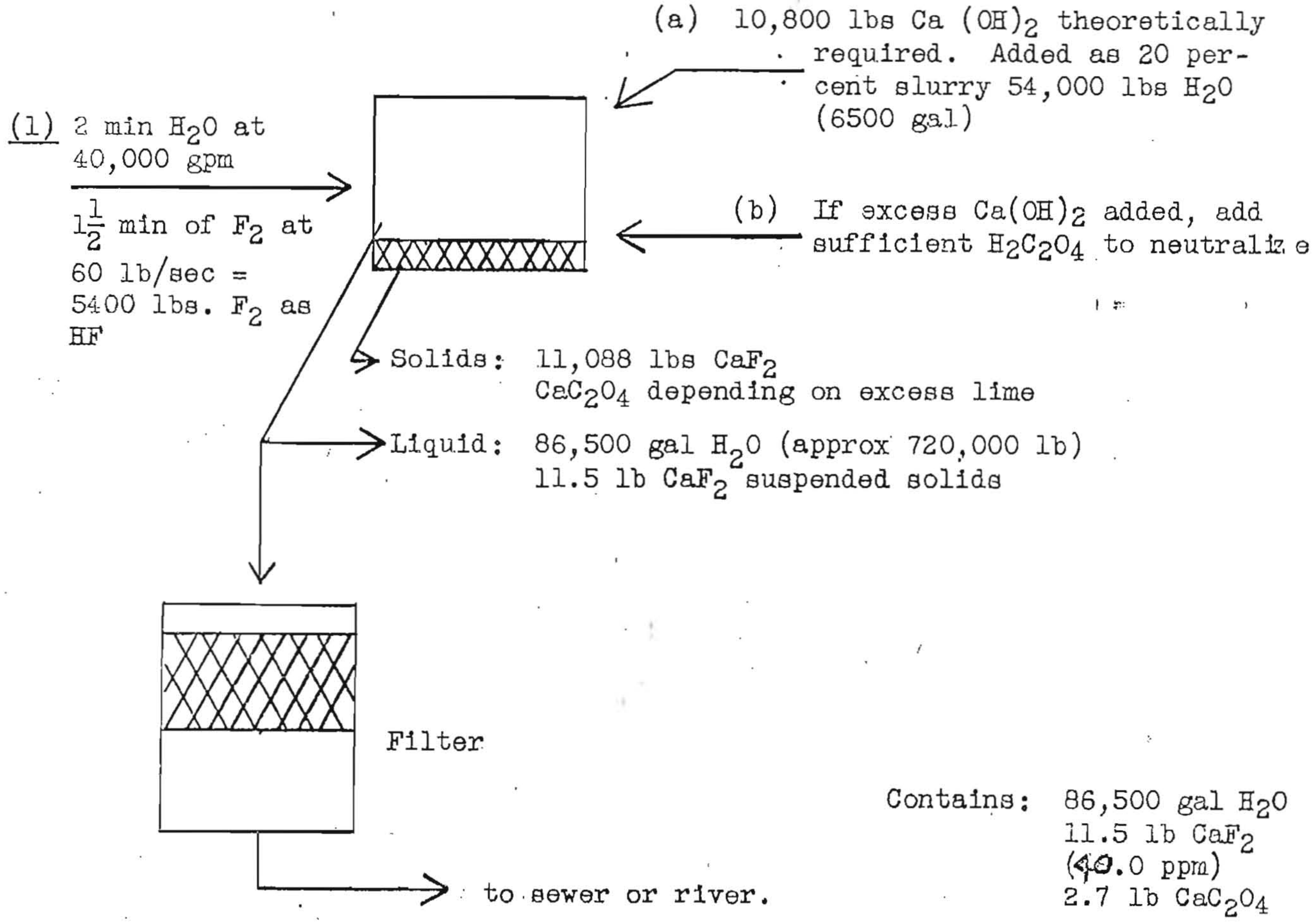
18. Phenols, not over 50 ppm.

19. Chlorides, not over 250 ppm.

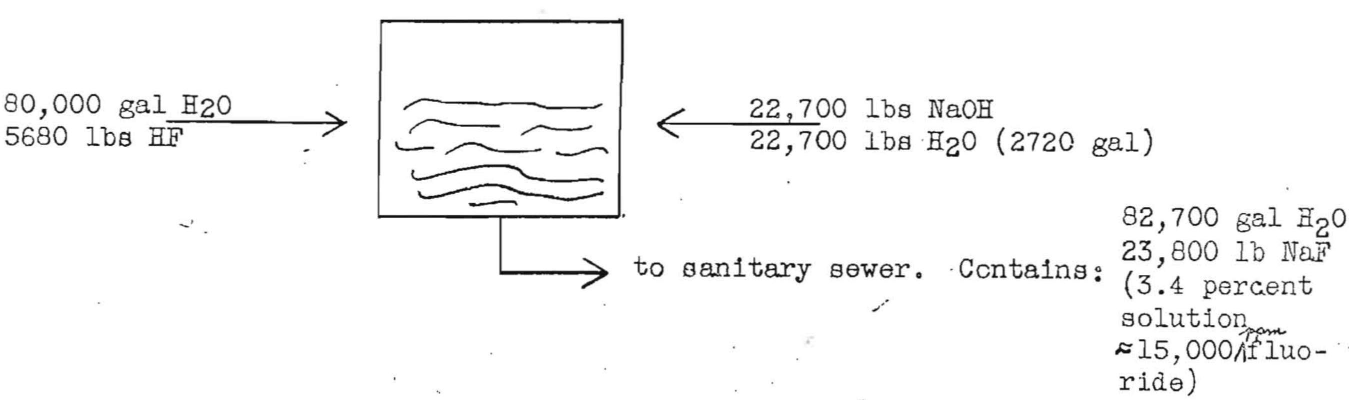
20. Sulphates, not over 300 ppm.

Adopted December 17, 1951.
By Laws, Rules and Regulations of the Board of Park Commissioners of the Clevelant Metropolitan Park District - 1952.

Approximate quantities involved in the above disposal schemes are noted below:



(2)



VI. Noise

A more complete analysis of the noise problem is contained in a memorandum by T. W. Reynolds dated April 25, 1954. The essential points are outlined herein.

The estimated sound power from a 20,000-pound-thrust engine is about 190 DB. The criterion for allowable noise level is shown in figure 3, from Bolt, Beranek, and Newman report, Revised Analysis of Noise Problem, Propulsion Science Lab., April 7, 1951.

The tolerable maximum sound intensity in the S-40 area is approximately 105 DB. A first consideration in maintaining the sound intensity below this level is that the exit velocity of the gases from the scrubbing stack be low enough that the sound generated at this source be below 105 DB. An estimate of the noise from this type of source may be made from figure 4. The maximum volume flow to be exhausted is 3550 cubic ft. per second. For various diameter ducts handling this volume flow, the estimated SPL would be:

Diameter, ft.	Exit velocity, fps	SPL, DB
10	45	105.4
15	20	91.5
20	11.3	82

In addition to the attenuation with distance, there is an estimated reduction of 6 to 10 DB possible due to directionality since the exhaust is directed upward.

The possible sources of attenuation within the duct are:

(a) Water sprays
(b) Expansion of the jet to final exhaust duct diameter
(c) Attenuation in straight duct
(d) Attenuation at duct bends
(e) Attenuation in packing and eliminator
(f) Attenuation by "sound stream" material if necessary

Analyses of above attenuation sources in reference memorandum indicate that sufficient attenuation will exist without need for adding any "sound-stream" absorbing material.

The sound intensity at the upstream end of the duct may be high enough that some sound absorbent treatment around the outside pipe wall is necessary. Present indications are that possibly 30 DB additional attenuation thru the upstream pipe wall may be required.

Use of the above duct system for a 100,000-pound-thrust engine will require the following additional considerations. The sound power level may be about 7-8 DB higher, thus requiring this much more attenuation thru the upstream pipe wall and in the duct.

The maximum volume flow of non-condensable gas is about 4700 standard cubic ft/sec.

Using an allowable sound intensity of 105 DB, the maximum allowable velocity out of the 20 foot diameter duct (from figure 4) is

$$105 = (SPL)_{curve} + 10 \log \text{area}$$

$$SPL = 80 \text{ DB}$$

or allowable velocity $\approx$ 33 fps. Therefore, the maximum allowable volume flow out is

$$(314)(33) = 10{,}400 \text{ cubic ft/sec}$$

The temperature to which the gas must be cooled, then, can thus be determined:

$$4700 \times \left(\frac{T}{460}\right) \left(H_T\right) = 10{,}400$$

where T = desired temperature of gas, ^oR

H = ratio volume wet gas to volume dry gas at saturation

at $T = 166^oF$ (626^oR), $H = 1.6$

$$4700 \left(\frac{626}{460}\right) (1.6) = 10{,}200$$

Therefore, the exhaust gases from the 100,000-pound-thrust engine will have to be cooled to this temperature (166^oF) to be below the allowable sound intensity of about 105 DB. This cooling load will require about 100,000 gpm water.

VII. Ejector Considerations

The rocket motor is to be connected to exhaust duct through a slip-seal so that induced air is not drawn into the duct by ejector action. The slip-seal has been used on a 5000-pound-thrust motor connected to a duct and demonstrated to have no effect on the thrust measurement. The purpose of the seal is to reduce the noise level and to lower the required gas handling capacity of the duct.

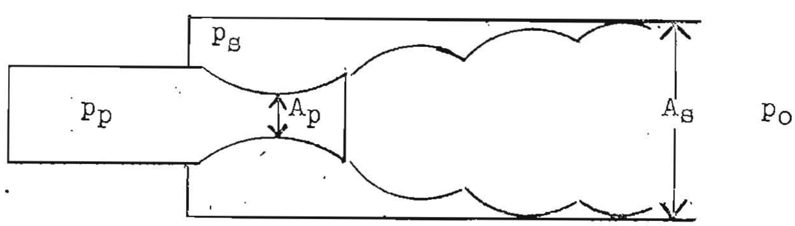
It is desired to have the exhaust duct large enough so that ejector action resulting from the high velocity rocket jet does not lower the pressure in the duct below about 3 to 4 psi of vacuum. This minimizes the correction for thrust to the motor and also is a less stringent structural requirement for the duct.

Consideration of the ejector relations as outlined in NACA RM E51E01 shows that in order to prevent low ejector pressures sufficiently high ratios of duct to engine throat area are required; the ratio should be large enough so that operation is in the region well below break-off pressure ratios, and is in a region where the ejector pressure ratio is a function of mixing and friction losses in the region of the expanding primary stream.

In this region

$$\frac{p_s}{p_o} \cong 1 - C\,\frac{p_p}{p_o}$$

where p_o is ambient pressure, p_p is the primary (or chamber pressure). p_s is the secondary (or duct pressure) and C is a constant dependent upon ejector configuration.



No experimental data with area ratios and pressures approaching the rocket conditions were found. Also, no data were available on the effect of adding water to the jet as required for the rocket exhaust. The theoretical work was extrapolated, nevertheless, to produce some curves predicting the expected ejector performance, and these are compared with some recent rocket runs with different sized exhaust ducts which result in a variation of the area ratio.

(1) Figure 5 was prepared and compared with some experimental data taken in Cell 23A. The ratio of duct area to engine throat area for this setup was small enough so that the pressure ratios were in the break-off region and ejector pressures were quite low. The data apparently conform to the predicted trend. The setup allowed some air to be drawn into the duct and no water was introduced into the exhaust jet.

(2) Figure 6 shows theoretical curves and the experimental data from Cell 14. The area ratio was large enough so that the pressure ratio was considerably below break-off region; the ejector pressure was not much below atmospheric. Some air was drawn into the duct and water was introduced to cool the exhaust jet.

(3) Figure 7 shows the theoretical curves and experimental points taken in Cell 11. This setup had the same area ratio (169) as will be obtained in the S-40 design during operation of a 100,000-pound-thrust engine. The ejector pressure was only 2 to 2.5 psi below atmospheric. For operation of smaller thrust engines, the expected $\frac{p_s}{p_o}$ would be higher (closer to atmospheric) than that shown in figure 7.

Both setups in Cells 14 and 11 had cooling water introduced into the rocket exhaust in approximately the same proportion to gas flow as planned for the new facility.

VIII. Electrical Power Requirements

The following power requirements are anticipated for the S-40 rocket facility:

1.	Hydrogen liquefier, compressors	350 HP	260 KW
2.	High pressure water coolant pump	300 HP	225
3.	Jet wheel pump	300 HP	225
4.	Ozone generator, 4.5 KW hr/lb ozone 10,000-12,000 volts Est at 30 lb/hr		135
5.	Water treatment pump	15 HP	11
6.	Compressors, helium and hydrogen	50 HP	38
7.	Instrument power		30
8.	Lighting (office, shop, test cells, instrument area, control bldg., outside)		50
9.	Power equipment (hoists, shop tools, etc.)		25
10.	Air compressor		10
11.	Liquid nitrogen pump		5
12.	Ventilation motors		25
13.	Miscellaneous transfer pumps	15 HP	11
14.	Refrigeration equipment		10
15.	Pump facility (possible future requirement)		1100
			2170 KW

X. Safety Features

A. Alerting and warning system. Colored flags will be flown over the test area to give visual indication of the conditions in the area:

Green - all clear

Yellow - hazardous operations in progress on stand, only personnel directly concerned with operation permitted in area

Red - dangerous condition - preliminary to firing - no persons permitted in area.

Barriers will be used for road blocks at the various approaches with colored light system similar to the flags at these locations.

Audio signals - part of the intercommunication system will consist of a public address system from the control room to all areas. A 5-minute warning by voice will be given over this public address system, and an intermittent low frequency signal sounded which will continue until the operation is completed. Thirty seconds before firing a siren will sound and continue until firing ceases.

B. Code detection system. Various detection devices will be connected in with the general laboratory warning system. These have not been worked out in detail yet.

C. Stand protection. Water deluge will be placed to completely cover all areas of the test stand where propellant fires can occur.

D. Storage area protection.

(1) General. Safety showers to be located in test area and ammonia and fluorine storage areas.

(2) Fluorine. A tank of 20 percent sodium hydroxide solution will be stored over the fluorine storage vessels, so that area can be deluged in case of fluorine tank rupture or serious leak. Tanks will be parked over a lime bed which will neutralize any HF formed. The area will be diked.

(3) Ozone. Will be treated as high explosive and hence stored in barricaded or magazine arrangement.

(4) Hydrogen. Liquefaction and storages will be made in the open, thus the very important factor of ventilation will not be a problem. OSM treats hydrogen as Class 950 which would require barricades to secure proper distances to other facilities.

(5) Ammonia. Water line for deluge in case of break in storage to be controlled from operations building.

(6) Hydrocarbons, alcohol and liquid oxygen. To be diked about storage tanks to contain the propellants in case of rupture.

E. Inside duct. Some water spray stations, in addition to that necessary for cooling and scrubbing, may be added to prevent any detonation from propagating more than a few feet. Experimental work is in progress to determine this requirement.

F. First aid stations and special equipment. The laboratory first aid station is approximately 4800 feet from the S-40 area.

All areas shall have a safety shower present.

Special safety clothing, helmets, etc. shall be provided for working in the hazardous areas and shall be stored in the small shop area adjoining the test stand.

XI. Intercommunication requirements

A. Public address system. Transmitter at control room of operations building; speakers located at (1) fluorine storage area, (2) hydrogen storage area, (3) ozone generation area, (4) test stand, and (5) in operations building, office area.

This system will be used for (a) paging, (b) to give instructions as to status of operation, and (c) may be used for other audio signal transmissions. Return transmissions from above area will be by way of interlab phone.

B. Six-way common communication between any combination of the following areas:

(1) main control room
(2) instrument room in operations building
(3) secondary control room in test stand
(4) instrument room in test stand
(5) test stand proper
(6) observation post

This system will be used in instrument check-out work, cold flow calibrations, pre-operation setups, and during firing.

C. Interlab telephones at

(1) each office
(2) control room of operations building
(3) instrument room of operations building
(4) shop of operations building
(5) shop on test stand
(6) fluorine storage area
(7) hydrogen generation trailer area
(8) ozone generation building

D. Ohio Bell telephone at

(1) Office of the Chief
(2) Pay phone in operations building

E. Warning signals to central laboratory point

Still to be decided upon -

F. Code call. To conform to the general laboratory policy.

IX. Instrumentation and Controls

1. The maximum numbers of each type of measurement are summarized as follows:

	Total No.	To Be Recorded*	Read at Control Room	Sensed For Automatic Control
Fluid Flow	16	16	12	2
Pressure	42	25	21	4
Temperature	138	26 [Up to 118 Intermittently Recorded with Rapid Switching]	32	0
Force	13	13	9	0
Liquid level	53	8	18	0
Valve position	28	0	20	0
Miscellaneous [Rpm, Power, Valve Rates, PH]	9	7	4	1

* Recording frequencies of 100 cps and in addition recording frequencies of 10,000 cps for 4 fluid flows and 10 pressures.

2. The following tables summarize all proposed measurements and give ranges and accuracies where possible. Also included are locations at which they are made, and if they are to be recorded, indicated directly for control, or sensed for automatic controls. The locations specified may be identified on a plot plan (present plan on dwg. CES 10312) and the circled numbers given with the locations are the key numbers on that plan.

TABLE I - FLOW RATES

Number of measurements	Location of measurements	Recorded at instrument center (1)	Read at control room (1)	Sensed for auto control	Maximum flows (lb/sec)	Accuracy (±%)
2	Propellant supply lines - test cell (2)	X	X As total & ratio of the two	Of propellant mass flow and mixture ratio at test cell (2)	F_2 - 68 O_2 - 76 H_2 - 24 H-C - 48 NH_3 - 64	1
2	Propellant supply lines - test cell (2)	X	- - - - - - -	- - - - - - - - - -		1
12	Cooling liquids and special propellants on research setup (2)	X	X	- - - - - - - - - -	Dependent on research setup	1

TABLE II - PRESSURES

Number of measurements	Location of measurements	Recorded at instrument center ①	Read at control room ①	Sensed for auto control	Range (psi)	Accuracy (± o/o)
1	H_2 gas manifold ④	------	X	Of H_2 compressor ⑮	0-3000	± 2
1	N_2 gas manifold ⑥	------	X	Of N_2 compressor ⑳	0-3000	± 2
1	He gas manifold ⑤	------	X	For He compressor ⑮	0-3000	± 2
2	Propellant tank pressurizing lines - test cell ②	------	X	----------	0-2000	± 1
4	At propellant flowmeters-test cell ②	X	-------	----------	0-1500	± 1
5	Exhaust duct ⑨	X	-------	----------	-5 to +5	± 2
1	Turbine gas generator-research setup ②	X	-------	----------	0-1000	± 1
3	Turbine gases - research setup ②	X	-------	----------	0-300	± 1
4	Cooling water - research ②	X	-------	----------	0-500	± 1
6	Fuel and oxidant research ②	X	-------	----------	(2) 0-1500 (4) 0-500	± 1
2	Turbine outlet fuel and oxid research ②	X	X	----------	0-1500	± 1
1	Engine ignitor - research ②	X	X	----------	0-1500	± 1
1	Combustion gas research ②	X	X	Of propellant flow rates	0-2000	± 1
2	LF_2 storage containers ⑯	------	X	Over-pressure to indicate on main lab central protection system	0-100	± 2
2	LO_3 storage containers ⑰	------	X		0-100	± 2
6	LH_2 storage containers ㉔	------	X		0-100	± 2

TABLE III - TEMPERATURES

Number of measurements	Location of measurements	Recorded at instrument center ①	Read at control room ①	Sensed for auto control	Range (psi)	Accuracy (± °/o)
20	Propellant tanks and flow lines - test cell ②	- - - - - -	X	- - - - - - - - - - - -	Ambient to -420° F	± 5° F
2	Propellants at flow-meter A - ②	X	X	- - - - - - - - - - - -	Ambient to -420° F	± 1° F
2	Propellants at flow-meter B - ②	X	- - - - - -	- - - - - - - - - - - -	Ambient to -420° F	± 1° F
8 Continuous recording	On research setup ②	X	- - - - - -	- - - - - - - - - - - -	Dependent on research setup	1° F or ± 1°/o whichever the greater
10 Continuous recording	On research setup ②	Up to 110 on 18 channels with rapid switching	X When continuous recording		"	
4	Gas and skin in exhaust duct - ⑨	X Could be rec. with rapid switching to read each meas. every 0.5 sec.	- - - - - -	- - - - - - - - - - - -	Ambient to 250° F	± 2° F

TABLE IV - FORCE

Number of measurements	Location of measurements	Recorded at instrument center ①	Read at control room ①	Sensed for auto control	Range (psi)	Accuracy (± o/o)
8	Weights of propellant tanks - test cell ②	X	X	------	Unknown at present	± 1
4	Engine thrust - on research setup ②	X	X As total of the 4	------	20,000 lb.	± 1
1	Missile tankage weight - on research setup ②	X	X	------	Unknown at present	± 1
1	Turbine exhaust - on research setup ②	X	------	------	0 to 500 lb.	± 1

TABLE V - LIQUID LEVEL

Number of measurements	Location of measurements	Recorded at instrument center 1	Read at control room 1	Sensed for auto control	Read at location of measurement	Accuracy (± °/o)
1	Ammonia storage 23	- - - - - -	- - - - - - -	- - - - - - - - -	X	
3	Hydrocarbon storage 2	- - - - - -	- - - - - - -	- - - - - - - - -	X	
6	Hydrogen storage levels 24	- - - - - -	- - - - - - -	- - - - - - - - -	X	
6	Nitrogen levels at H_2 stor. 24	- - - - - -	- - - - - - -	- - - - - - - - -	X	
2	Liquid oxygen storage 18	- - - - - -	- - - - - - -	- - - - - - - - -	X	
5	F_2 storage levels 16	- - - - - -	- - - - - - -	- - - - - - - - -	X	
5	N_2 levels at F_2 storage 16	- - - - - -	- - - - - - -	- - - - - - - - -	X	
2	Ozone and N_2 at ozone storage 17	- - - - - -	- - - - - - -	- - - - - - - - -	X	
5	Nitrogen storage 19	- - - - - -	- - - - - - -	- - - - - - - - -	X	
8	Main propellant tank levels test cell 2	X	X	- - - - - - - - -	- - - - - - - - - -	1
8	Liquid nitrogen in propellant tank baths 2	- - - - - -	X	- - - - - - - - -	- - - - - - - - - -	1
1	Exhaust water basin 11	- - - - - -	X	- - - - - - - - -	- - - - - - - - - -	2
1	Lime slurry tank 10	- - - - - -	X	- - - - - - - - -	- - - - - - - - - -	2

TABLE VI - VALVE POSITION
INDICATION (ALL INDICATING AT CONTROL ROOM 1)

Number of measurements	Valve location
1	Coolant pump inlet - test cell 2
1	Water reservoir - 8
15	Water lines of exhaust duct - 9
1	Lime slurry tank 10
2	Propellant control valves - test cell 2
8	Pressure control valves - test cell 2

TABLE VII - MISCELLANEOUS

Measurement	No. of measurements	Location of measurement	Recorded at instrument center (1)	Read at control room (1)	Sensed for auto control	Read at location of measurement	Range (psi)	Accuracy (± o/o)
Rotary speed	1	On research setup - (2)	X	X	- - - -	- - - - - - -	0 to 50,000 rpm	± 2
Shaft horse-power	1	On research setup - (2)	X	- - - -	- - - -	- - - - - - -	0 to 600 HP	- - - -
Electric power	2	On research setup - (2)	- - - - - - -	X	- - - -	- - - - - - -	Dependent on research	± 2
Valve opening rates	4	On research setup - (2)	X	- - - -	- - - -	- - - - - - -	- - - -	- - - -
PH	1	Outlet of exhaust water basin (11)	X	X	Of neutralizing acid flow rate	X	1 - 14	- - - -

3. Automatic control of the flow of oxidant and fuel, so as to result in the desired ratio of the flows and combustion pressure in the rocket engine, is an essential need for the new facility. Present methods of controlling these flows by the use of calibrations and manual regulationof the pressure of the gas which forces the propellants to the engine have been very unsatisfactory. It is common with present setup to obtain a spread in flow ratios of 20 percent or more when attempting runs at constant ratio, and similar variations in chamber pressure often occur. For the new facility, which will handle high flows of costly propellants, failure to obtain desired values by suitable controls would result in great losses of money. For instance, one second of operation with Fluorine as the oxidant will cost more than $800.

Because no equipment is available commercially to solve this control problem it has been requested that research be initiated as soon as possible to develop a system and demonstrate its use on a rocket test facility. In view of relative difficulty and urgency of need, it has been suggested that the development be made in three phases: (1) automatic control of each propellant flow to set values; (2) automatic control of propellant flows to set total while maintaining a selected flow ratio; and (3) automatic control of engine combustion pressure by control of propellant flows while maintaining a set flow ratio.

The requirements of the control system are as follows:

(1) Individual flows maintained with ± 2.5 percent; total flow, combustion pressure, and flow ratio within ± 3.5 percent.

(2) Obtain full flow from zero flow in 0.5 second (if this requirement is too severe the time may be increased).

(3) It is desired that the controls be fully damped. If this is not possible within 0.2 second (preferred) to one second, a partially damped system with overshoot not exceeding 10 percent of full flow would be acceptable with the final setting stabilized within 0.2 second.

It has been proposed that the control devices be developed using the facilities of cell eleven of the rocket laboratory and 500-lb. thrust engines. Maximum flows of the propellants would be 18 lbs. per second of liquid oxygen and 8 lbs. per second of JP fuel.

4. General Specifications

A. Data recording. - In general, it is required that some of the recording be adaptable for rapid check on data as a monitor on operations and that most of the recording be as advanced as possible from the standpoint of data reduction.

B. In consideration of future expansion it is desired that the recording system be planned so that individual switching of instruments to circuits from more than one location be possible.

C. An automatic propellant flow control system which would vary flow ratio over desired ranges during a run, while maintaining a constant combustion pressure, would be desirable if lags in measurements of flows, thrust, and combustion pressure are not large enough to result in large inaccuracies in determinations of characteristic velocity and specific impulse.

D. Remote engine controls are required which will involve the setting of pressure regulators and the positioning and opening and closing of valves. Sequence timing of most of these controls will be required. Pressure-actuated permissive and automatic cut-off devices will be used in the control system; some temperature-actuated devices may also be necessary.