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NO. 3 OF 49 SERIES A

LEXINGTON PROJECT REPORT

No. 31

MEETING WITH NEPA GROUP AT LEXINGTON

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Jerry E Keyes
Authorizing Official
Date 3-5-98

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NAME: Jerry E. Keyes
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Lexington Project Report # 31

Title: Meeting with NEPA Group at Lexington
Date: June 21, 1948
Notes by: W. C. Cooley

Summary: Presents data for the NEPA subsonic inhabited and supersonic inhabited and uninhabited aircraft. Summarizes discussion with NEPA representatives on aircraft design, reactors, shielding, and materials.

A general meeting was held with six representatives from NEPA:

A. Kalitinsky
R. E. Adams
K. C. Cooper
G. D. Cremer
A. Mason
D. Poole

Kalitinsky presented answers to several questions which had not been answered previously. Design studies of three types of aircraft, (inhabited supersonic, inhabited subsonic, and uninhabited supersonic) are to be made before attempting the design of an experimental reactor. These studies may require two years for completion. At present, the analysis of the supersonic uninhabited turbojet missile is proceeding and the report may be completed about September 1948.

SUPERSONIC UNINHABITED MISSILE

The design data for this missile are as follows:

Flight Mach No. = 1.5 (V = 995 m.p.h. at 40,000 ft.)
Power plant: 4 turbojet units
Compressor pressure ratio = 16 (excluding diffuser ram)
Turbine inlet temp. = 1800°F
Turbine diameter = 3.44 ft.
Reactor material: UC_2 and graphite
Core diameter and length = 4.35 ft.
Reflector thickness = 13.5 in. (around sides of cyclinder)
Free-flow ratio = 0.30
Max. wall temp. = 2500°F
Max. reactor power at sea level = 220,000 kw.
Max. reactor power at 40,000 ft. = 132,000 kw.
Static thrust at sea level = 48,000 lb.
Max. thrust (at 40,000 ft. and M = 1.5) = 20,300 lb.

Assuming a pessimistic coating of .010 in. Si C and 10% impregnation of Si C in the reactor core:
Dilution ratio C/U = 950
Uranium investment (90% enriched) = approx. 100 lb.
Reactor operates on the boundary of epithermal energy

Assuming an optimistic coating:
Dilution ratio C/U = 2000
Uranium investment (90% enriched) = approx. 50 lb.

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Reactor is fairly near thermal

Compressor efficiency (assumed) = 85%
Turbine efficiency (assumed) = 86%
Nozzle efficiency (assumed) = 95%
Reactor pressure drop = 17% of stagnation pressure at compressor outlet.
Pressure drop in reactor inlet duct and reflector = 3%
Pressure drop in reactor outlet duct and reflector = 5%
Diffuser ram efficiency (assumed) = 90%
Pressure ratio due to ram = 3.2
Air flow rate (total for 4 units) = 540 lb./sec.
Air flow rate (one unit at 35,000 ft.) = 160 lb./sec.
L/D for entire airplane = 4.25
Reactor hole diameter = 0.40 in.
Gross weight = 87,000 lb.
Reactor weight (core and reflector) = 25,000 lb.
Pressure shell wt. = approx. 3000 lb.
Payload wt. = 12,000 lb.
Turbine & compressor wt. = approx. 20,000 lb.
Compressor power = approx. 50,000 HP.
Reactor element design: 19 holes per hexagonal brick
Side reflector cooling air required = 1% of total air flow

The supersonic uninhabited aircraft was designed so that the shift of the center of gravity would be small when the bomb was dropped, so the plane could return to its base if desired.

INHABITED SUBSONIC

For the inhabited subsonic aircraft, the determination of shielding weight required is so uncertain at present that the design study and optimization cannot be completed. Approximate shielding calculations have omitted the effect of secondary gamma rays. Bethe's method for a hydrogenous shield has been used to estimate a minimum shield weight. An estimate of the maximum shield weight has been obtained by calculating the absorption of only primary neutrons from a point source with no self-shielding. For a four-foot shielded diameter, the minimum weight estimate is 76,000 lb. and the maximum weight is 288,000 lb. for a homogeneous mixture of tungsten and boron ("W B_6") to reduce radiation intensity to 1 r per hour at 33 feet. The actual shield might be made of tungsten carbide and boron carbide with a density of 6.5 gm./c.c. NEPA believes that the actual shield weight may be about 150,000 lb.

Present data for the subsonic inhabited aircraft are:

Mach No. = 0.8 to 0.85 at 35,000 ft.
Structural efficiency (shield wt./gross wt.) = 50%
Airplane L/D = 20
Required thrust = 15,000 lb.
Compressor pressure ratio = 50
Turbine inlet temp. = 1800°F

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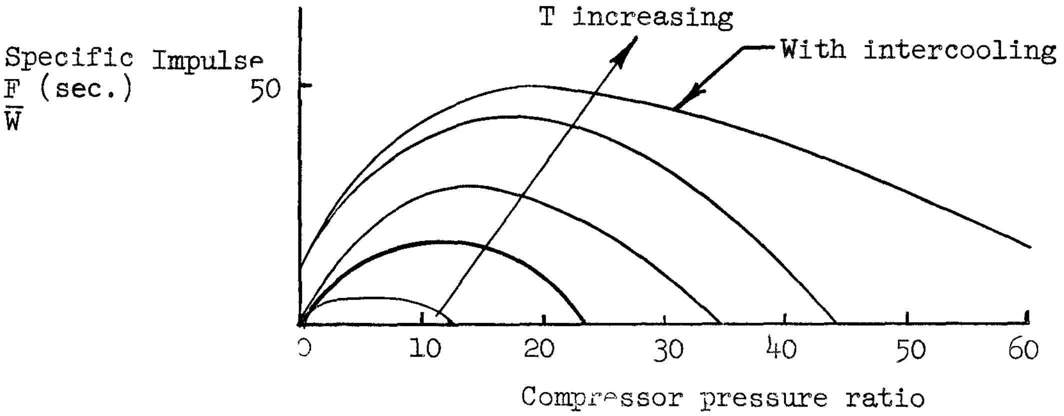
Thrust per unit reactor free flow area = 10,000 lb./sq. ft.
Free flow area = 1.5 sq. ft.
Free flow ratio = 0.30
Reactor core diameter = 2.5 ft.
Reflector thickness = 9 in.
Atomic ratio C/U = 150:1
Uranium investment (cold, uncontaminated) approx. 120 lb.
Uranium investment (hot) = maybe 240 lb. (Guess)
Reactor hole diameter = $\frac{1}{4}$ in. to 3/16 in.
Thermal stress = about 250 psi for 3/16 in. hole
The reactor outlet ducts are not shielded.

<u>INHABITED SUPERSONIC</u> (Best estimates)

Reactor shielded diameter = 4 ft.
Gross weight = 300,000 lb.
Airplane L/D = 6 to 8
Thrust = 40-50,000 lb.
Overall pressure ratio (with ram) = 90
Thrust per unit free-flow area = about 20,000 lb./sq. ft. (or between 15,000 and 24,000 lb./sq. ft.)
Free-flow ratio = 0.4
Reactor core diameter = 2.5 ft.
Atomic ratio C/U = 80
Uranium investment = 200 lb.
Thermal stress = 300 to 350 psi (Guess)

This turbojet will have easier starting conditions because there is no flame and no surging of flow-rate. The design of this unit is based on an estimate of the probable development of the chemical turbojet projected ahead 5 to 8 years. The limitations on range may be the necessity for reprocessing of uranium and the coating life. NEPA plans to set up a small pilot plant for chemical reprocessing and refabrication of fuel elements.

Poole sketched a plot of turbojet specific impulse (thrust per unit air flow rate) against compressor pressure ratio for various turbine inlet temperatures:



The upper curve shows the improvement attainable by using intercooling for high pressure ratios. For the inhabited subsonic aircraft an intercooler effectiveness of 60% was used.

If the turbine inlet temperature were lower than 1800°F, the gross weight and uranium requirements would probably be greater. At some inlet temperature around 1400°F the net thrust would drop to zero.

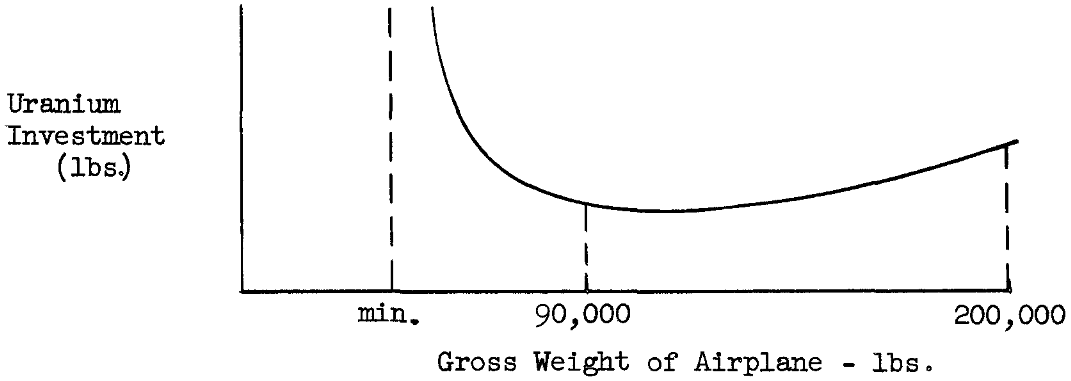
REACTOR HEAT TRANSFER:

The reactor exit Mach number is around 0.4. Calculations have assumed a power production which is uniform radially and a cosine distribution axially. Attainment of a nearly uniform radial distribution may require 1.2 times as much uranium. The maximum wall temperature is 2500°F. and the maximum interior temperature is about 2700 or 2800°F. Air flowing through a 19-hole fuel element goes into an adapter to a single hole of the same total area which extends through the reflector. The 3% inlet pressure drop and 5% exit pressure drop include losses in this reflector ducting up to the actual heating section. (core)

NOTES ON MEETING OF POWER PLANT GROUP WITH POOLE, COOPER, AND ADAMS:

The closed-cycle power plant may not be applicable at supersonic speeds. It is more complex than the open-cycle system and may not require the type of ceramic reactor development which would allow eventual extension to the ramjet and rocket. With the open-cycle turbojet, fewer new components are under test at one time. The heat rejection is about four times as bad for the closed cycle as for the intercoolers of an open cycle. NEPA has concluded that the optimum condenser volume would be the maximum that could be enclosed in the wing and fuselage without introducing extra nacelles. These condensers may give a net ramjet thrust. NEPA believes that about 1 sq. ft. of condenser frontal area can be installed per 10 sq. ft. of wing area.

Adams sketched a curve of uranium investment against gross weight for the supersonic uninhabited aircraft.



An airplane weight of 87,000 lb. was chosen to get a small uranium investment.

Poole pointed out the uncertainty in predicting compressor and turbine efficiencies for high pressure ratio turbojets.

AFTERNOON MEETING WITH NEPA GROUP

Kalitinsky stressed the lack of reliability of a closed-cycle plant in case the cooling system were hit by a bullet. Without cooling, the reactor would evaporate. Design of a closed-cycle plant looks extremely unattractive.

Using a liquid metal coolant such as Na-K or Pb-Bi with a reactor wall temperature of 1700°F may be very serious metallurgical problem because of diffusion and formation of solid solutions. The metallurgy of liquid metals is not well enough known to predict a design.

Shapiro discussed the high-pressure helium cycle, which looks more promising from the standpoint of the coating problem than any other cycle. He mentioned the possibility of helium pressures around 500 atm., but Kalitinsky pointed out the difficulties of sealing against leaks at a pressure of even 1000 psi. For the same free-flow area, helium may produce 2.5 times as much power as air for the same pressure and pressure drop.

Friedman discussed the effect of free-flow area on shield weight. Decreasing the free-flow ratio from 0.3 to 0.2 may save 25 tons of shield weight.

Discussion of materials problems and thermal stress:

Prof. Norton remarked that thermal stresses may not be as serious at high temperatures because the material may creep. Annealing compensates for radiation damage at high temperature.

Hunter stated that graphite reaches a saturation radiation damage after about 60 kw. hr./c.c. The missile reactor at 130,000 kw. would be subjected to only about 8 kw. hr./c.c., in a 10-hour mission. BeO reaches saturation after 4 to 5 kw. hr./c.c.

Kalitinsky mentioned graphite or beryllium carbide as possible moderator materials for the rocket. The fuel might be UC_2 with only a small amount of moderator. Hunter suggested the possibility of platinum tubes through graphite at 1700°F temp. for the closed cycle.

The increase of uranium required for the NEPA design, when operating, over that for the cold reactor was broken down as follows:

Factor of 4 due to coating
Factor of 1.8 for control system

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Remaining factor for temperature effect and poisoning. (Factor of 1.4?)
Soodak calculated a factor of 7.5 due to a platinum coating.
Kalitinsky listed the NEPA materials contractors who are now active:

Battelle Memorial Institute -- fuel rods and coatings, porous materials, Be_2C
Fansteel Metallurgical Corp. -- metallic coatings
Ohio State Univ. -- metal-ceramic coatings
A. O. Smith -- ceramic coatings
Norton -- tungsten and boron carbide
Univ. of Minnesota -- solid equilibrium of U, C, and Be
Univ. of Michigan -- high-temperature creep of C and Be_2C at 2500°F and possibly 3000°F.
Iowa State -- synthesis of materials, measurement of physical properties.
Northrop -- stability of ceramics in hydrogen at high temperatures (project completed)
Armour Foundation -- high temperature, thermocouples

In reply to Friedman's questions on shielding, Kalitinsky replied that the secondary gamma method has worked out. Northrop has studied back-scattering and absorption of gammas in air for shadow-shielding design. Bulk shielding samples of tungsten and boron carbide are to be tested in the Clinton pile.

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