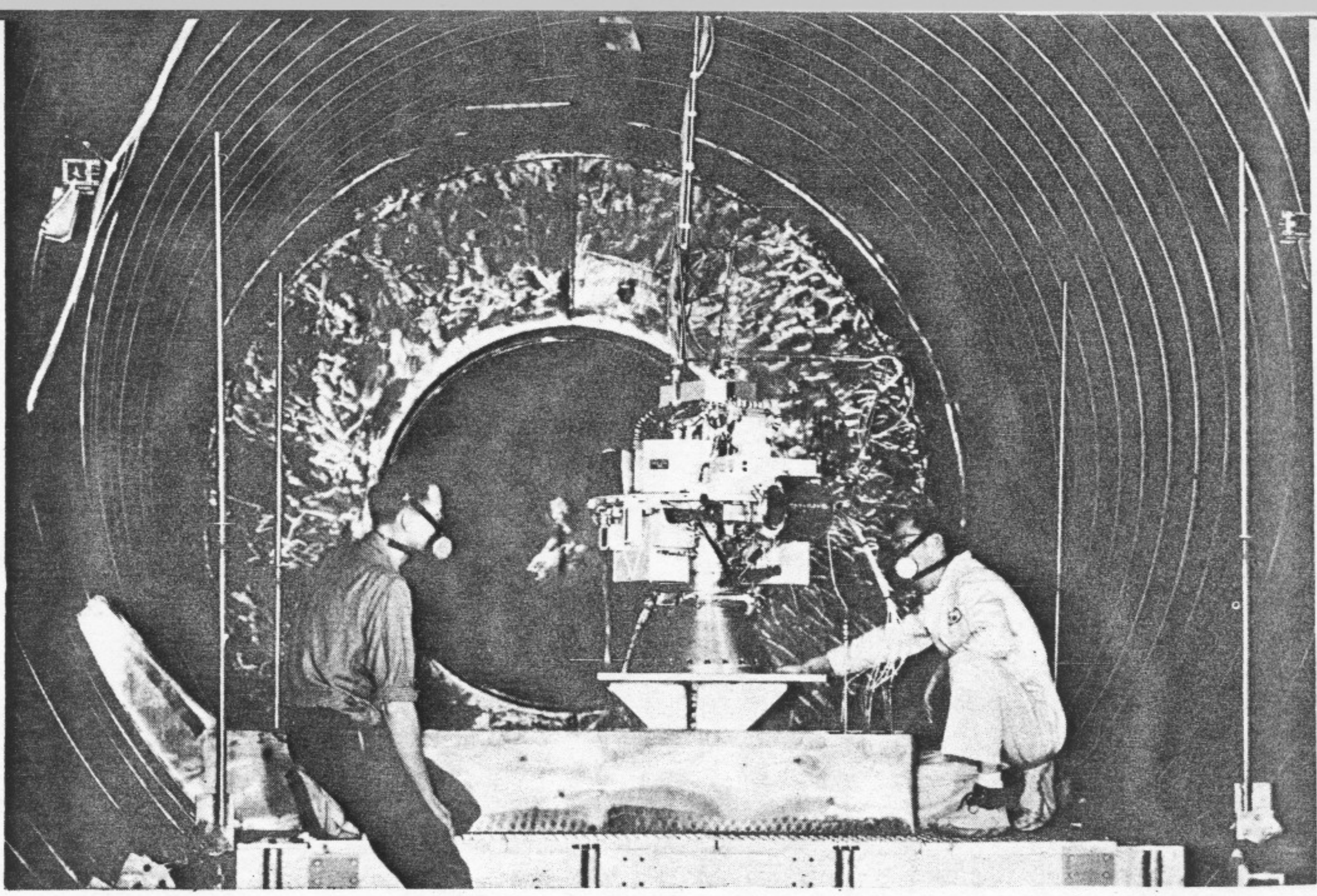


SPACE ELECTRIC ROCKET TEST flight package is set up by National Aeronautics and Space Administration technicians in a space simulation chamber at NASA's Lewis Research Center for a trial run. Package contains cesium contact ion engines developed by Hughes Research Laboratories and Lewis, and includes battery power supply and power conditioning equipment.

Electric Propulsion—Part 1:

Electric Rocket Program Being Reshaped

By Michael L. Yaffee

New York—United States' electric propulsion program is having trouble getting off the ground. Failure of the December, 1962, Air Force flight test of an ion engine—the first and only flight test of an electric thruster in this country (AW Jan. 7, 1963, p. 37)—revealed some serious technical problems which forced delay and curtailment of flight test plans.

Money has been another problem. Although more money than ever before —approximately $15 million/year—is now being spent on electric thruster research and development, those in the program say it is less than half of what is needed and is relatively small when compared to the funding of nuclear thermal rockets. Moreover, declares one top nuclear electric rocket engineer, the money is being spent on a multitude of component research programs instead of on the development of integrated systems.

Test Difficulties

Although the Air Force has never spelled out the reasons for the failure, the flight test apparently ran into difficulties with outgassing of the battery and other non-thruster components, and a problem of incompatibility between the ion thruster and the power converter.

It is believed that at the time, the Air Force had planned a series of flight tests for arc-jet and plasma engines as well as more ion engine tests. Except for a repeat try of the Electro-Optical ion thruster flight, it now appears that virtually all of those plans have been put aside. The Air Force currently is spending $2.7 million a year on electric thruster research and development and says that its effort in this field has leveled off but not gone down.

The National Aeronautics and Space Administration, which is spending about $12 million a year on research and development of electric rocket thrusters, also braked its flight test plans during the past year and reshaped its thinking on some efforts in this field.

NASA's double-barreled Space Electric Rocket Test (SERT 1) of two ion engines—its own and one from Hughes Aircraft Co.—originally scheduled for November, 1961, has been postponed several times. Currently undergoing an expanded ground test program, it is not expected to fly before the third quarter of 1964. SERT 2 and 3 flights, slated for 1965 and 1966, have been postponed indefinitely.

NASA Effort

NASA is working in most of the same areas of electric rocket propulsion as the Air Force, but has not classified its programs. It readily admits that plans ran into major problems of outgassing and incompatibility, and that these were the principal reasons for the latest re-

Propulsion Chart

A key part of this series on electric propulsion is a table on pp. 16-17 giving a detailed breakdown of electrostatic, electrothermal and electromagnetic propulsion programs. The story continues on p. 18.

scheduling. Of the two problems, NASA considers the more important one to be that of incompatibility between the ion thruster and the high power converter which is designed to take the power from the battery and convert it to the proper voltage and current for the ion engine.

Both SERT 1 ion engines were qualified using dummy power converters. But about a year ago, when scientists at the Lewis Research Center tried to run the engines in a vacuum chamber with flight power converters, they discovered the basic incompatibility problem.

RCA Work Resumed

At this point, NASA slowed the Radio Corp. of America's work on the first flight capsule, and turned to the problem of converter incompatibility with Thompson Ramo Wooldridge (TRW), which is supplying power conditioning equipment for testing. This problem has now been solved, according to NASA, and RCA's work on prototype and flight capsules has again been accelerated.

(The Air Force says only that it has an active power conversion program aimed at defining requirements and the interrelationship of converter and thruster characteristics.)

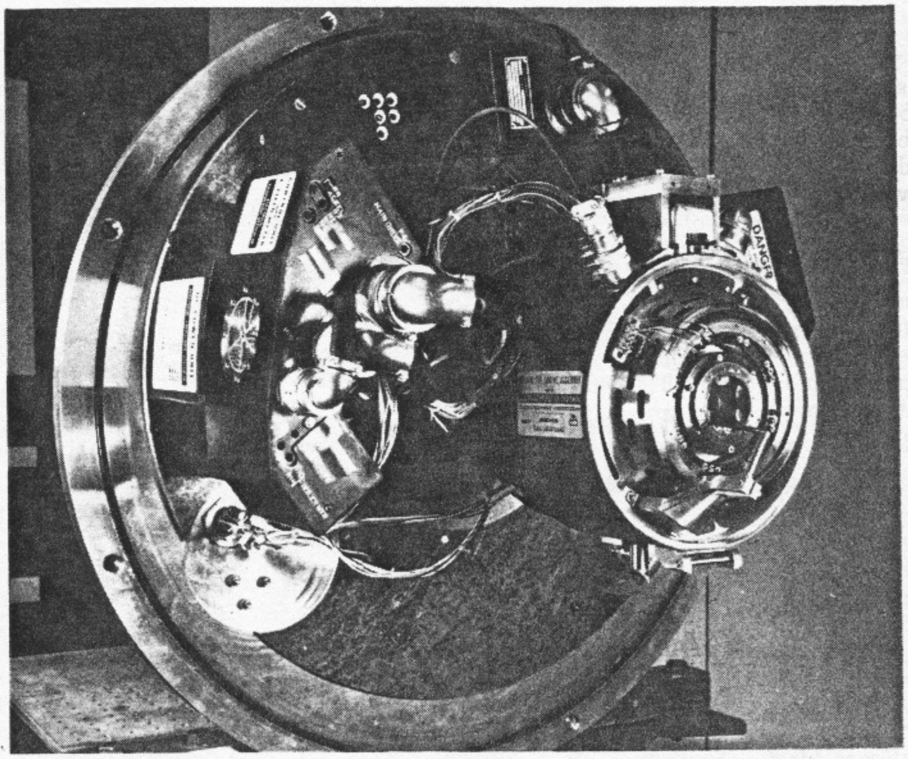
Outgassing, not entirely unrelated to the converter problem, posed a still serious if somewhat lesser concern. NASA says it was aware of this as a potential problem area. With a drop in ambient pressure down to the near vacuum of space, some gas was expected to evolve from materials in the flight package. The gas in this case—appearing to come mostly from the battery power supply—evolved in amounts large enough to cause a voltage breakdown and local arcing capable of burning out vital components.

Problem Solved

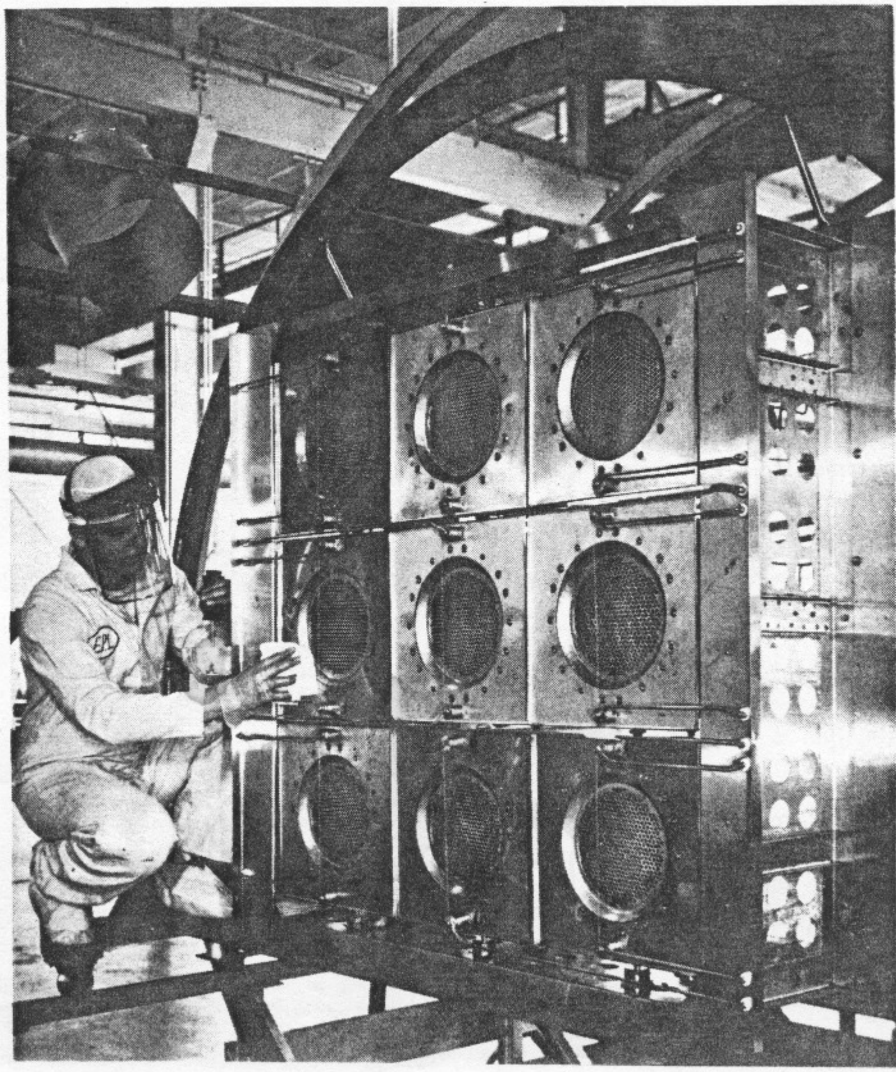
Scientists at Lewis have tried to pinpoint all possible sources of outgassing in the first flight capsule. For the flight test, these areas will be sealed at ground pressures or vented adequately so that pressures will drop rapidly through the critical outgassing levels. Materials which decompose badly under the vacuum and temperature conditions of space will be replaced where necessary.

In any event, both NASA and the Air Force believe they also have solved this problem and don't expect to run into any other major ones which could force further postponement of ion engine ballistic flight tests.

The Air Force, in fact, is reportedly ready to try its next test from Pt. Arguello, Calif., in the first quarter of this year. It will again use a Blue Scout



NINE-ENGINE ARRAY, mounted 3x3, of Kaufman ion engines was invented, designed and perfected at NASA's Lewis Research Center. Lewis is actively studying problems of clustering many such low-thrust electric engines for deep space flights. Hughes Research Laboratories' cesium contact ion engine, below, has had its housing pod removed to show the 3-in. diameter annular engine and power conditioning subsystem. The engine was developed for NASA's Space Electric Rocket Test series.



Breakdown of Electric Propulsion

Electric rocket engines are low thrust devices—using electricity to heat or accelerate a propellant to very high specific impulses of approximately 1,000 sec. and beyond.

Their greatest value will be in space, beyond the maximum pull of planetary gravity, where a small amount of thrust will move large and "heavy" objects. In space, their own mass will amount to little and, owing to their high specific impulse, they will operate on relatively small amounts of propellant.

Because these low thrust, high impulse electric engines will not produce enough thrust to lift themselves off the earth's surface, they will require large, high thrust chemical booster rockets to put them in their proper medium.

Complete electric rocket engines will consist of propellant feed and metering systems; electric thrusters or accelerators; power sources—which initially will be batteries and solar cells, and later, nuclear reactors, and power conditioning or conversion equipment.

Depending on how the propellant or working fluid is accelerated, electric rocket propulsion systems are generally classified as electrostatic, electrothermal or electromagnetic.

Electrostatic systems use static electric fields to accelerate an ionized propellant.

Electrothermal thrusters heat the propellant electrically. It is then expanded through a nozzle to produce thrust.

In an electromagnetic accelerator, the interaction of a magnetic field and an electric current produces an electromagnetic body force which accelerates the charged particles in the plasma working fluid.

Electrostatic Thruster Programs

COMPANY	THRUSTER	PROPELLANT	POWER (kw.)	THRUST (mlb.)	SPECIFIC IMPULSE (sec.)	CONVERSION EFFICIENCY (%)	STATUS	FUNDED BY
Cosmic, Inc.	colloid	oils, liquid metals	.006	1	200	85	R, D	NASA
Electro-Optical Systems, Inc.	contact	cesium	n.a.	n.a.	n.a.	n.a.	D	USAF
	bombardment	cesium	3	12–15	4,000–7,000	n.a.	R, D	NASA
General Electric	plasma separator	cesium	2.5	n.a.	10,000	90	R, D	NASA
Hughes Aircraft	contact	cesium	.61	1.6	9,000	51	F.Q.	NASA
	contact	cesium	2.9	15	6,000	70	D	NASA
	contact	cesium	.5	1.5	4,500	30	P	NASA
	contact	cesium	.15	.5	4,500	33	P	NASA
	bombardment	mercury	n.a.	n.a.	6,000–9,000	n.a.	R	NASA/company
Ion Physics Corp.	bombardment	xenon	.37	1.05	8,700	75	D	company
	bombardment	argon	.44	.7	16,000	62	D	company
	colloid	mercury	n.a.	.1	n.a.	n.a.	R	company
NASA	bombardment	mercury	1.4	6.4	5,000	50	D	in-house
	colloid	mercury-chloride aluminum-chloride	5	n.a.	2,000–8,000	n.a.	R	in-house
Rocket Power, Inc.	colloid	solids	.1	n.a.	2,000–5,000	n.a.	R	NASA
TRW Space Technology Laboratories	contact	cesium	n.a.	n.a.	n.a.	n.a.	D	USAF
	colloid	glycerol	.05	1	1,000–5,000	95	R	USAF
Tapco linear	bombardment	mercury	.5	2.8	9,000	82	R, D	NASA
annular	bombardment	mercury	.4	2.3	5,000	64	R, D	NASA

Electrothermal Thruster Programs

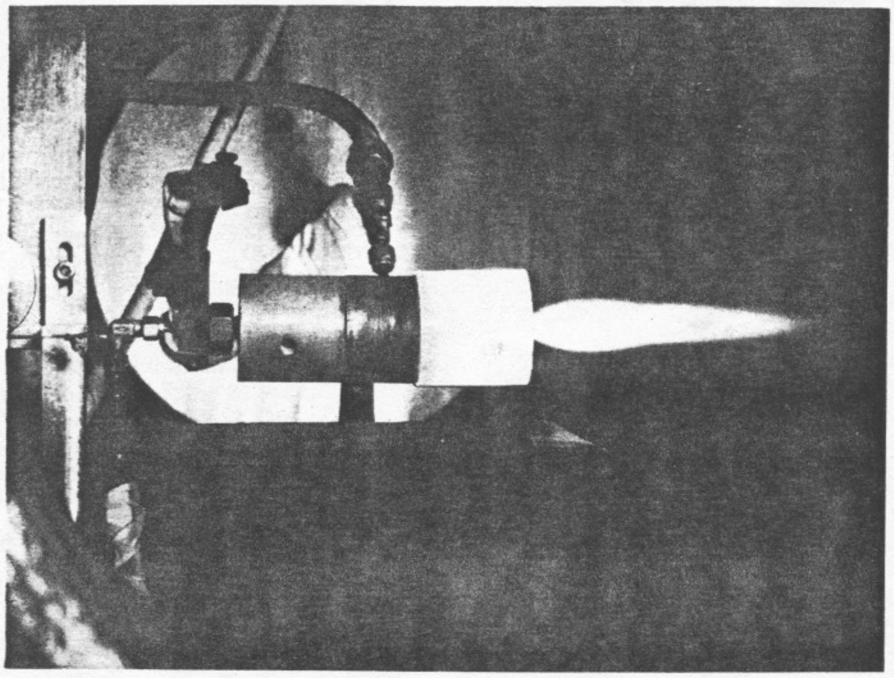
COMPANY	THRUSTER	PROPELLANT	POWER (kw.)	THRUST (mlb.)	SPECIFIC IMPULSE (sec.)	CONVERSION EFFICIENCY (%)	STATUS	FUNDED BY
Avco Corp.	Arc-jet	ammonia, hydrogen	30	250–500	750–1,500	35–40	R, D	NASA
	resistance jet	hydrogen	2–3	100	750–800	70	R, D	NASA
Electro-Optical Systems, Inc	arc-jet	hydrogen	>100	n.a.	>1,000	n.a.	R	USAF
General Electric	3-phase, a.c. arc-jet	hydrogen	30	550	1,050	43	R, D	NASA
	resistance jet	hydrogen, ammonia	<1	1–100	300–600	n.a.	D	company
Giannini Scientific Corp.	arc-jet	hydrogen	30	n.a.	n.a.	n.a.	D	USAF
	resistance jet	hydrogen	3	n.a.	n.a.	n.a.	R	USAF
NASA	resistance jet	hydrogen	3–15	100–500	900	60	D	in-house
Space Dynamics Corp.	arc-jet	hydrogen	30	250–500	2,000–2,500	40–70	R	NASA

rograms for Space Applications

Electromagnetic Thruster Programs

COMPANY	THRUSTER	PROPELLANT	POWER (kw.)	THRUST (mlb.)	SPECIFIC IMPULSE (sec.)	CONVERSION EFFICIENCY (%)	STATUS	FUNDED BY
Allison Div. General Motors	rail accelerator	non-alkalai metals	25	110	2,000–10,000	35–50	R, D	company
Avco Corp.	magnetic annular arc	ammonia, argon, helium, hydrogen, nitrogen	30	333	1,800–2,000	n.a.	R	USAF
	various plasma accelerators	argon	3–150	500	1,500–4,000	35	R	USAF
Electro-Optical Systems, Inc.	Hall current accelerator	argon, helium, nitrogen	300	250	2,000–3,500	30	R	NASA
General Dynamics/ Astronautics	coaxial gun	argon, helium, neon, nitrogen	150	n.a.	3,500–10,000	35	R, D	NASA/company
General Electric	coaxial gun	argon, helium, nitrogen	54	70	5,500	42	R, D	NASA
General Technology Corp.	traveling wave accelerator	noble gases	>100	100–250	2,000–5,000	n.a.	R, D	NASA
Giannini Scientific Corp.	thermionic	hydrogen	50–200	110–400	2,000–7,000	n.a.	R	USAF
MHD Research, Inc.	crossed field accelerator	argon	70	660	1,000	20	R, D	NASA
NASA	coaxial gun	argon, hydrogen, nitrogen	depends on mission	1	3,000–10,000	35	R	in-house
	traveling wave accelerator	argon	26	1	3,000	15	R	in-house
		xenon	26	4	4,000	25	R	
	Hall current accelerator	argon	.2–.4	n.a.	2,000–5,000	10–15	R	in-house
	magnetic expansion thruster	arbitrary	.12	<2	1,000–5,000	25	R	in-house
Northrop	crossed field accelerator	argon, nitrogen, nitrogen-oxygen	100–1,000	10,000	1,200–3,000	20	R, D	USAF/company
Radio Corp. of America	electron-cyclotron resonance accelerator	mercury	.1	n.a.	1,000	30	R	USAF/company
Republic Aviation	plasma pinch engine	hydrogen, nitrogen	.03	n.a.	n.a.	n.a.	R, D	USN
	plasma pinch engine	hydrogen, nitrogen	1	1–3	1,500–7,000	30	R, D	company
United Aircraft	oscillating-electron ion engine	arbitrary	.1–.2	>1	1,000–5,000	25	R, D	USAF/company

R=research D=development P=prototype F.Q.=Flight Qualified mlb.=millipound (1/1,000 of a pound)
kw.=kilowatt (1,000 watts) <=less than >=greater than
n.a.=not available because of military or company classification, not applicable or not yet determined



UNCOOLED, 30 KW. ARC-JET thruster (above), developed under NASA contract by Avco's Research and Advanced Development Div., has completed a 720-hr. qualification test run. The unit dissipates 10,000F temperatures entirely by radiation. Thrust is between ½-1 lb. RCA plasma accelerator (below) is a continuously operating RF device called an electron-cyclotron resonance accelerator. Microwave power is transferred selectively to the plasma electrons at electron-cyclotron resonance.

rocket to carry an EOS battery-powered, cesium-contact ion engine on a ballistic trajectory designed to provide the engine with at least 25 min. of operation.

NASA plans to provide an additional safety margin of flexibility for its coming Blue Scout-SERT 1 shot from Wallops Island, Va., which will be a ballistic trajectory designed to provide 50 min. of engine operation time.

Intended primarily to test ion beam neutralization, the flight is set up so that the Hughes ion engine will operate for 25 min. and shut down. The NASA engine then will run for 25 min. NASA, however, said it will be able to command one engine to operate should trouble develop with the other.

Larger Payloads

Subsequent orbital flights, which will require a Thor-Agena or a Thor-Delta booster, will be considerably more expensive because of the bigger vehicle and larger payload, and therefore will demand a correspondingly greater assurance of success.

Before it was postponed, SERT 2 called for a 6-12 month orbital flight test of a 2-3 kw. electrical rocket engine powered by a solar cell panel. But after NASA scientists ran into the converter incompatibility problem in SERT 1, they weren't sure they had adequate reliability in either the converter or thruster to assure a six month operational life.

Consequently, they decided to delay the flight and selection of a project contractor until they could check out everything—including the actual need at that time for such a flight test—in an expanded ground test program which is expected to run through Fiscal Year 1965.

The same reasons applied to an even greater degree to the third Space Electric Rocket Test, which was to be an orbital ion engine to be used for station keeping and attitude control applications.

Expanded Ground Test

About the time NASA was ready to select a contractor for the program, some scientists began weighing the ion engine's potential in these applications against that of much less costly chemical rocket engines.

For an ion engine to pay off in those applications, many felt it would have to operate reliably for at least three years. As a result, NASA decided it would be better to spend a year or two in an expanded ground test program to improve the reliability of the ion engine, and at the same time to more fully evaluate its attitude control and station keeping potential in relation to that of the chemical rocket engine.

Another factor that appears to be playing an important role in revised planning of the electric rocket area by both NASA and Air Force is the lack of progress in the development of suitable, large nuclear power sources and conditioning equipment. High temperature, corrosion and weight problems in the development of large power supplies are significantly more formidable than first anticipated.

Electric rocket thruster work is far out racing power supply development, according to those involved in the electric program. Several scientists predict it will be at least 10 years before megawatt power packages needed for primary propulsion are available.

Even when the relatively modest, 30 kw. SNAP 8 nuclear reactor becomes operational, it probably will prove to be a valuable testbed but it won't be good enough for operational electric rocket engine flight systems, electric thruster sources said.

Among other effects of this lag is the reorientation of thruster programs to lower power levels where, operating from low power batteries and solar cells, they can compete for more immediate applications such as station keeping and attitude control.

The lag also has played a part in the curtailment and stretchout of thruster development and flight test programs. A number of project engineers maintain that there is now plenty of time for ground testing, and see no reason to hurry when there are no power supplies coming along.

Similarly, the lag has probably played some role in the Air Force's de-emphasis of work on electromagnetic rocket engines. Plasma thrusters are expected to look more attractive at high power levels.

Evaluate Potentials

And, again, with no suitable power supply in sight there is no need to push development and plenty of time to establish the basic physics and diagnostic techniques still needed in the plasma area.

The Air Force says only that electromagnetic propulsion is a complex field and offers no promise of first generation thrusters. It now believes that electrostatic and electrothermal thrusters show about equal potentials for first generation applications with electrostatic thrusters leading the pack in terms of their potential for second-generation uses.

Accordingly, the Air Force says it is de-emphasizing its electromagnetic propulsion work and increasing support of electrostatic propulsion while maintaining interest in electrothermal propulsion at about the same level.

The Air Force also reports that it now is limiting the number of thrusters it will try to cover, so that it will be involved in fewer specific projects but with more money for each.

Over-all NASA funding of electric rocket thruster research and development rose again in Fiscal 1964 but is expected to level off in Fiscal 1965. Funding of thruster development, as opposed to research, has stayed at the $8 million level for three years. Similarly, there has been no shift in emphasis—NASA is still putting most of its money into the development of the ion thrusters it believes show the most immediate promise.

NASA, now starting 500-hr. duration tests of ion thrusters, will concentrate during the coming year on learning more about increasing lifetimes and clustering in the ion field. The emphasis in electrothermal thrusters will be on raising specific impulses. In the area of plasma accelerators, NASA will continue its search for a device that will give reasonable efficiency and lifetime while helping provide fundamental knowledge.

(The second part of this series, covering electrostatic rockets, will appear in a subsequent issue.)

Biosatellite Experiments Selected

Washington—National Aeronautics and Space Administration has selected 14 experiments for the first Biosatellite flight to be made late next year. The first flight will last three days and will end in recovery of the experimental capsule, now being developed by General Electirc (AW Dec. 30, p. 20).

First set of experiments will weigh about 50 lb. and will consist of pepper plants, wheat seedlings, amoeba, frog and sea urchin eggs, bread mold, fruit flies and embryonic beetles. They will be studied after the flight to determine the combined effects of radiation, zero gravity and absence of the earth's rotation.

Five more Biosatellites will follow, most of them carrying chimpanzees and other large biological specimens on missions lasting up to 30 days.

Experiments in the first satellite, selected jointly by NASA's space sciences and advanced research offices, are:

- **Pepper plant growth,** in which the angle between leaf and stem will be measured. Experimenter is Dr. James C. Finn, Jr. of North American Aviation.
- **Wheat seedling root** and shoot growth and cell division. Three experiments in this general category were proposed by Drs. Stephen W. Gray and Betty Edwards of Emory University, H. M. Conrad and S. P. Johnson of North American, and Charles J. Lyon of Dartmouth College.
- **Amoeba nuclei division** and the evolution of food vacuoles, an experiment by Drs. R. W. Price and Donald E. Ekberg of Philadelphia, and E. W. Daniels of Argonne Laboratory.
- **Radiation effects** on bread mold, an experiment by Dr. F. J. DeSerres of Oak Ridge National Laboratory.
- **Radiation effects** on beetle eggs, by Dr. John V. Slater of the University of California.
- **Cell division** of fertilized frog and sea urchin eggs. These two experiments were proposed by Dr. Richard S. Young of Ames Research Center, which is NASA's manager for Biosatellite.
- **Radiation effects** on male wasps, to be mated after recovery. Dr. R. C. Von Borstel of Oak Ridge Laboratory is the experimenter.
- **Color changes** and cell death in the flowering plant tradescantia, proposed by Drs. A. H. Sparrow and L. A. Schairer of Brookhaven Laboratory.
- **Radiation effects** on latent bacteria virus, proposed by Drs. Rudolf H. T. Mattoni of North American and William T. Romig of the University of California at Los Angeles.

MOL Test Subjects Experience Mild Bends

San Antonio—Mild cases of bends were experienced by three of four subjects during the first of a series of 50 tests by the USAF School of Aerospace Medicine here to determine the suitability of a 50% oxygen-50% nitrogen environment for the Air Force's manned orbiting laboratory (MOL) on missions of 60 days or longer.

Symptoms of the bends appeared immediately as the subjects began exercises in an altitude chamber simulating extra-vehicular activities, such as performing tasks outside a spacecraft or moving from the Gemini B spacecraft to the laboratory portion of the MOL. The experience was described as brief, disappearing as the subjects concluded the exercise.

Tests are each of 10-hr. duration, in five phases. In the first phase, the subjects breathe pure oxygen through face masks for 1½ hr. to purge all nitrogen from their systems. Next, they enter a high-altitude chamber, still breathing pure oxygen.

Pressure in the chamber is reduced to equal 27,500 ft. altitude pressure. Subjects remain in this environment for 2½ hr. Still breathing pure oxygen, they are taken to 35,000-ft. altitude in the chamber and exercise strenuously for 15 min., doing deep knee bends and push-ups. This is to determine whether bends will occur despite the previous de-nitrogenation and to reveal other stresses that might be encountered in moving from the Gemini B to the MOL.

The 35,000-ft. environment at pure oxygen is considered similar to that provided by a pressure suit, but provides the suited subjects with full mobility. Cabin atmosphere is established at 18,000 ft., and the un-masked subjects breathe the mixed-gas—50% oxygen-50% nitrogen—environment for 4 hr.

This period is considered sufficient to permit their bodies to absorb the amount of nitrogen equal to a 60-day or longer mission.

In the final phase, the pressure suits are again simulated by lowering cabin pressure to 35,000 ft. Subjects breathed pure oxygen through face masks. Subjects exercise for 2 hr. doing deep knee bends and push-ups at the rate of five every 15 min. This portion of the test is to determine whether the nitrogen absorbed in the body during the MOL environment will cause bends.

It was in this final phase that three of the four subjects in the first test experienced mild symptoms of the bends as they started their exercises.