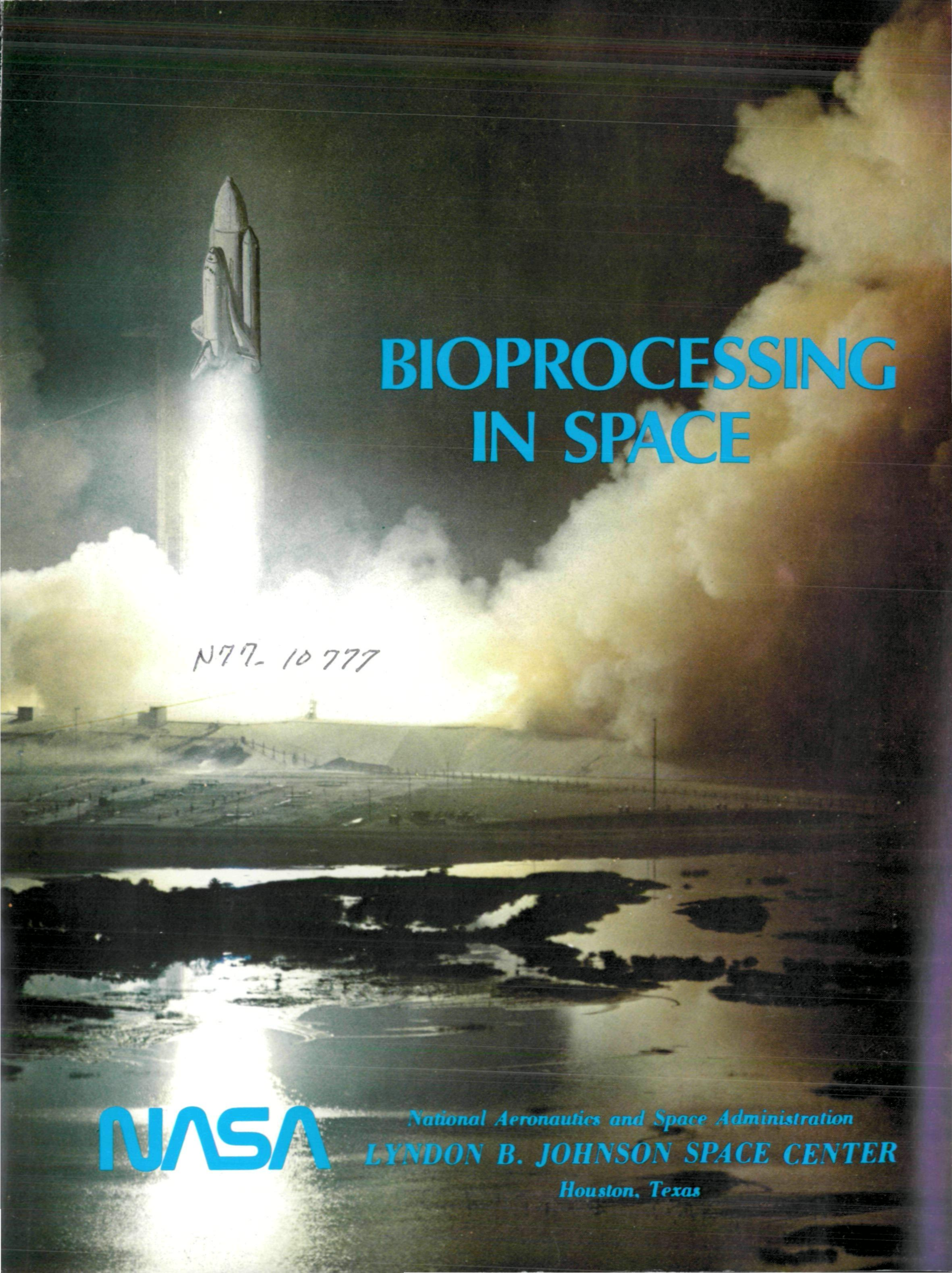


BIOPROCESSING IN SPACE

NASA

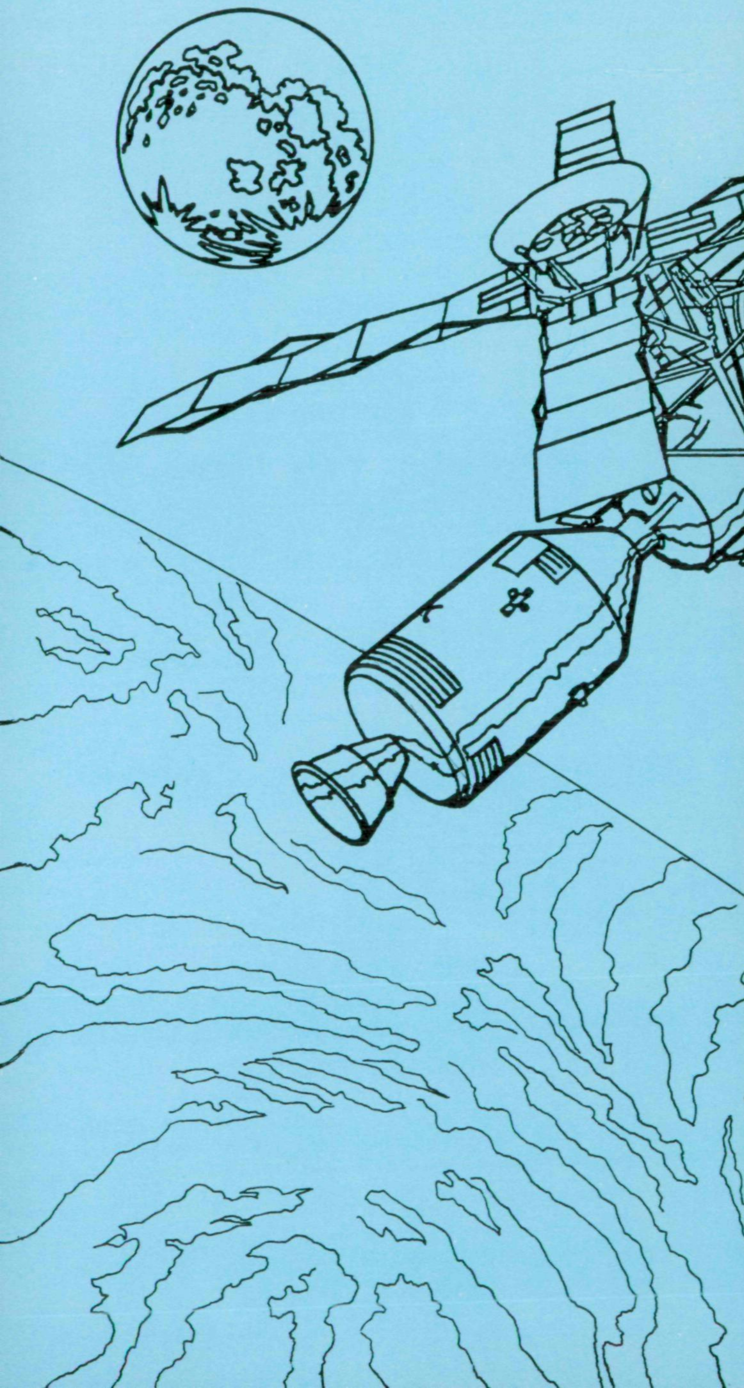
National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

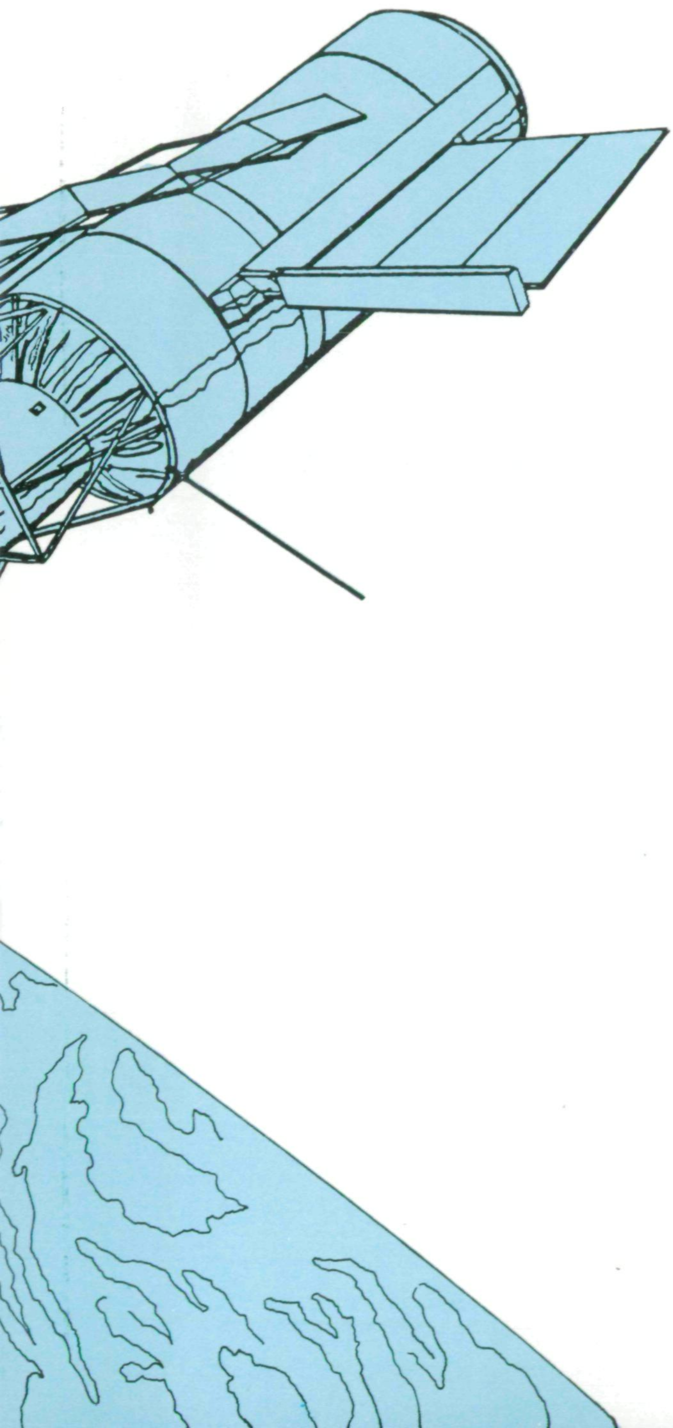
The cover illustration, showing the launch of a Shuttle spacelab, symbolizes the use of space to initiate an era of technological development and expansion for the benefit and profit of all mankind.

The assistance of the Boeing Company (Under Contract NAS9-13655) is acknowledged.

You are invited to participate...

in the development of biological and biochemical technology for processing and manufacturing in space.





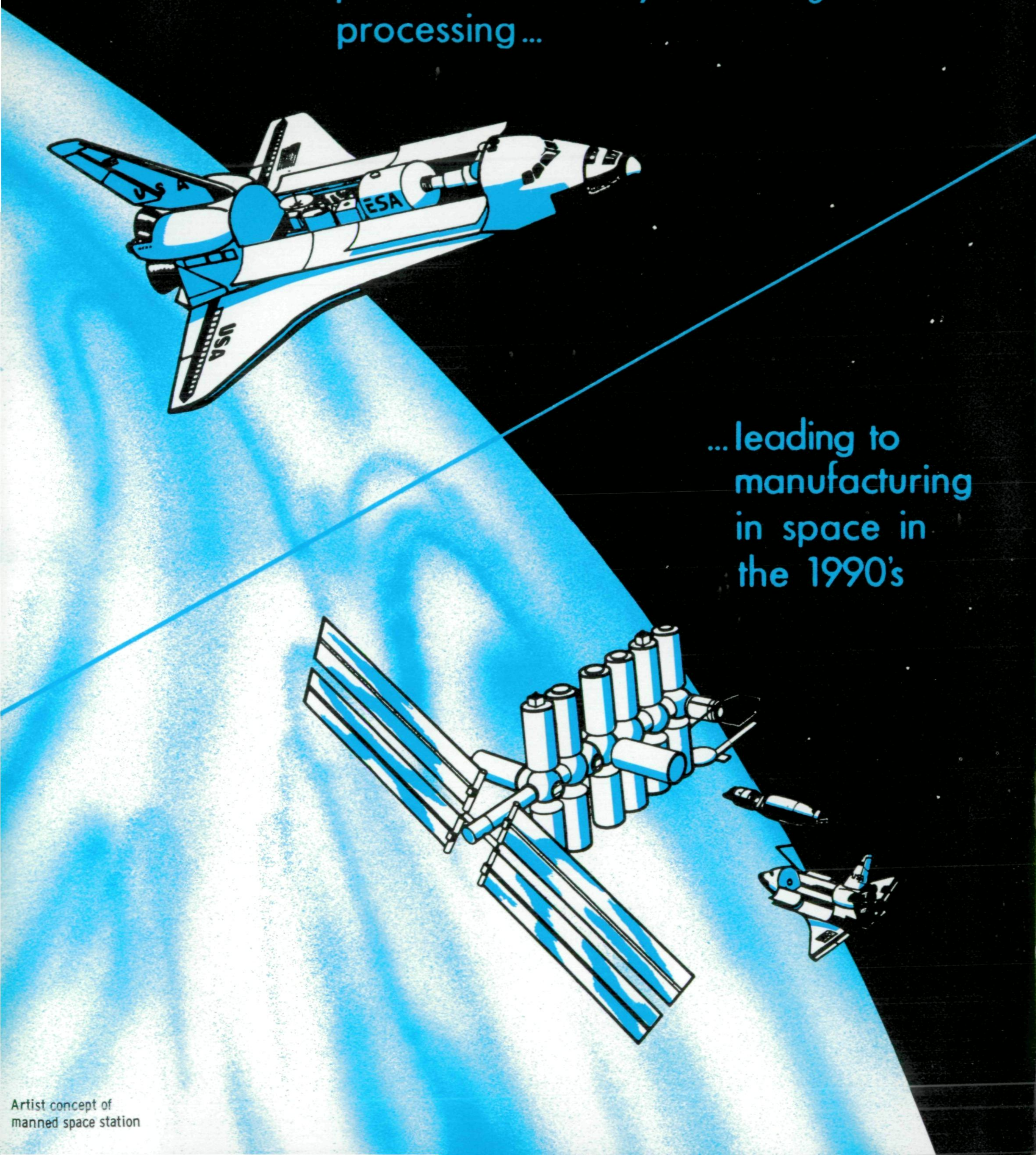
Experiments conducted during Apollo and Skylab flights have shown that many materials have unique properties in the absence of gravity. Unexpectedly, results from a third of the Skylab experiments are likely to cause improvements in existing materials technology.

The data from Skylab flights also indicate that materials which cannot be produced on Earth may be purified, isolated or manufactured in space.

Our current aim is to examine the potential of space bioprocessing and to encourage your active participation in the development of new concepts in this field.

Christopher C. Kraft, Jr.
Director, Johnson Space Center

Shuttle and Spacelab experiments in the 1980's will be designed to prove the feasibility of biological processing...



...leading to manufacturing in space in the 1990's

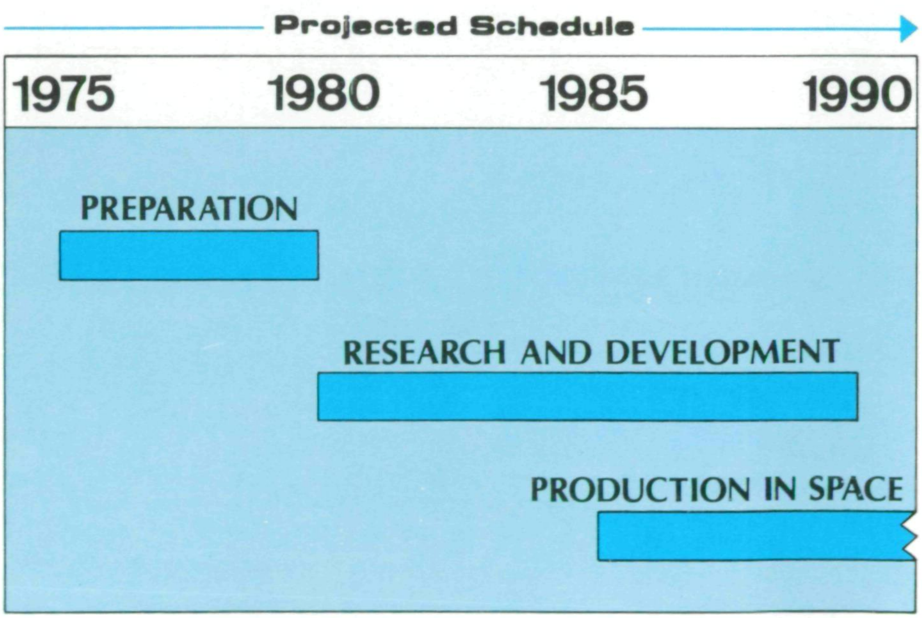
Artist concept of manned space station

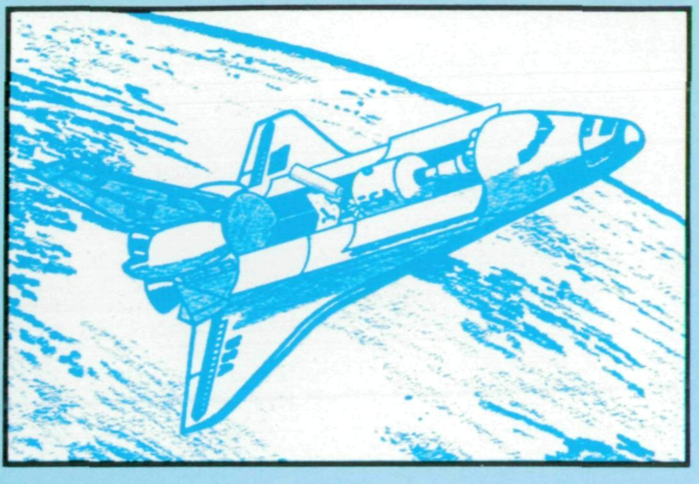
Projection

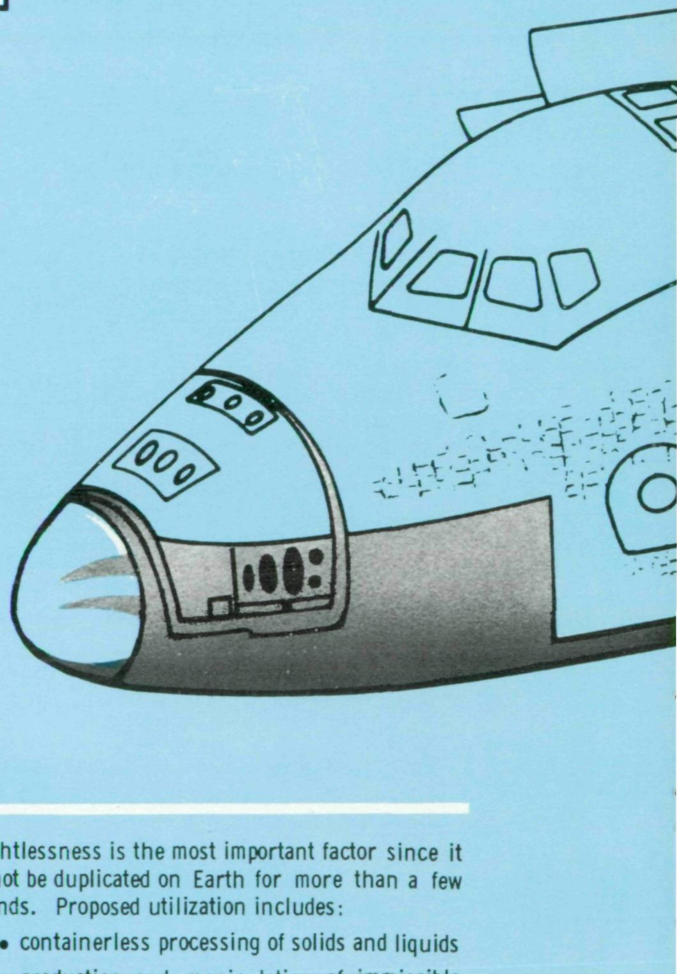
Technological findings of manned space flight will be amplified and used in the Space Shuttle Era to serve future needs of science and applications on Earth.

The operational goal of the Space Shuttle Program is to provide low cost transportation to and from Earth orbit. In the 1980's, experiments will be performed in Spacelabs which will be carried on the Shuttle. The flights will last from 3 to 30 days, and many scientists will have the opportunity to fly with their experiments.

The Space Bioprocessing Program is designed to explore the possibility of accomplishing bioprocessing and manufacturing that is too difficult, costly or impossible to accomplish on Earth.





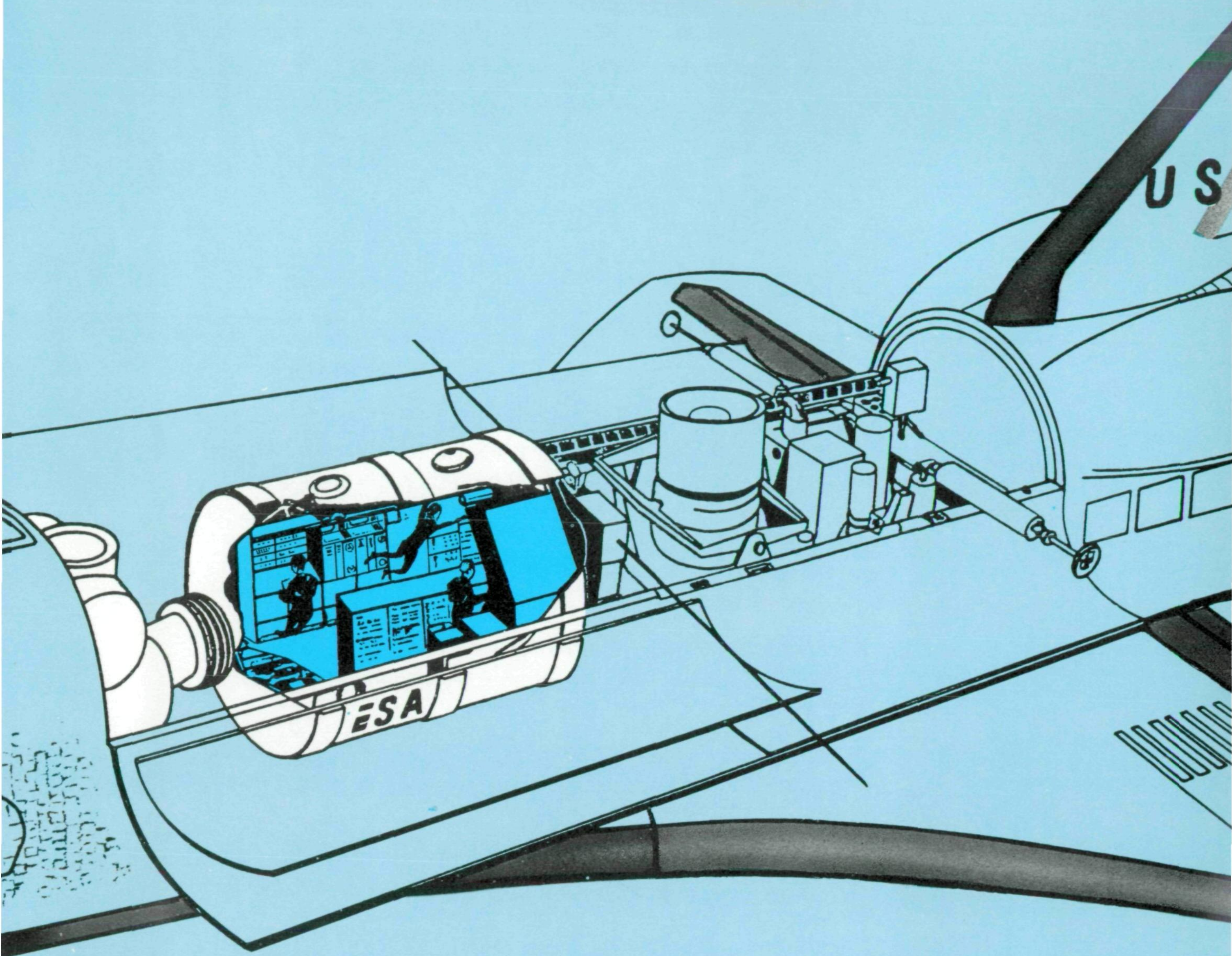


SPACE ENVIRONMENT

Experiments in space can be conducted in conditions of virtual weightlessness, with the additional advantages of readily available solar energy and a vacuum source of unlimited capacity.

Weightlessness is the most important factor since it cannot be duplicated on Earth for more than a few seconds. Proposed utilization includes:

- containerless processing of solids and liquids
- production and manipulation of immiscible mixtures
- processes which benefit from convectionless behavior of weightless fluids
- electrophoresis or other separation methods which are more efficient in the absence of gravity.



SPACELAB CHARACTERISTICS

The Shuttle Orbiter will carry the Spacelab in the cargo bay. Living quarters will be provided in the Orbiter with access to the Spacelab module through a tunnel.

The Spacelab module, configured as a pressurized cylinder 6.9 meters (22.6 feet) long and 4 meters (13.1 feet) in diameter, will serve as a manned laboratory with a shirtsleeve-type environment for a crew of three payload specialists. A Spacelab pallet is an unpressurized platform also located in the cargo bay; instruments not requiring a pressurized environment are mounted upon it.

The Spacelab can be varied as required: for example, a module only, a pallet only, or a combination of both.

SOME IMPORTANT FINDINGS FROM SPACE EXPERIMENTS

DID YOU KNOW?

- On Skylab, gravity levels ranged between 10^{-6} and 10^{-9} g. The low gravity environment of space offers the possibility of eliminating or controlling convection.

- In the near zero-g conditions of space,

  - unrestrained liquid masses formed free-flying globules which could be tethered with a thread or needle

  - vapor bubbles grew virtually without limit in boiling liquids

  - flames from burning materials were quickly extinguished by a buildup of combustion products.

- A dispersion of two immiscible liquids was at least 3.6×10^5 times more stable in space than on Earth.

- Liquid films formed from soap solutions lasted considerably longer in low-g than in Earth-gravity experiments.

- Reduced gravitational stresses on intermolecular bonding produced abnormally large crystals with near perfect structure.

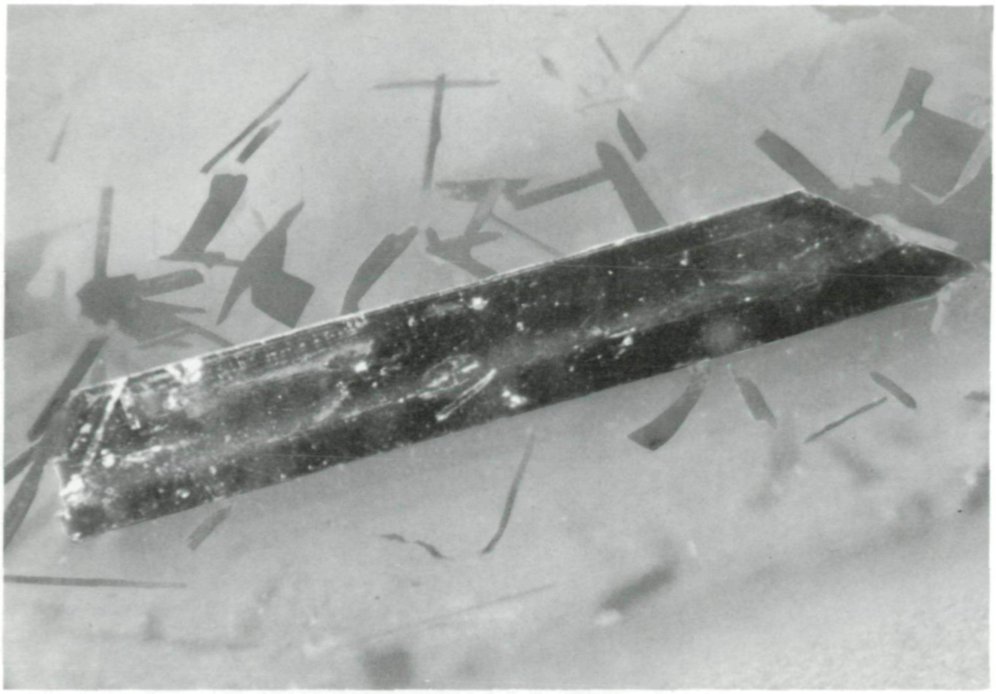
- A vacuum in the range of 10^{-11} to 10^{-13} N/m^2 has been measured in the space environment.

Space experiments have already resulted in new advances in Earth-based materials technology and industrial production methods

PHYSICAL EFFECTS

The following three Skylab experiments demonstrated unique physical phenomena:

Large Germanium Selenide Crystal grown on Skylab



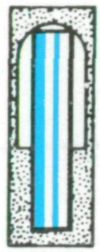
Space-grown germanium selenide crystals had an almost perfect structure and superior quality to crystals grown on Earth. In addition, one crystal (18mm) was six times larger than expected. This may be due to the null gravity state which kept the crystal in a favorable orientation toward the source of the vapor.

Vapor crystal growth technology on Earth will be advanced as a result of the experiments carried out during Skylab missions.

PHYSICAL EFFECTS

Diffusion and the shaping effects of surface tension and adhesion were
Skylab experiments. These effects were exploited to form a semiconductor

Indium Antimonide Crystal Growth

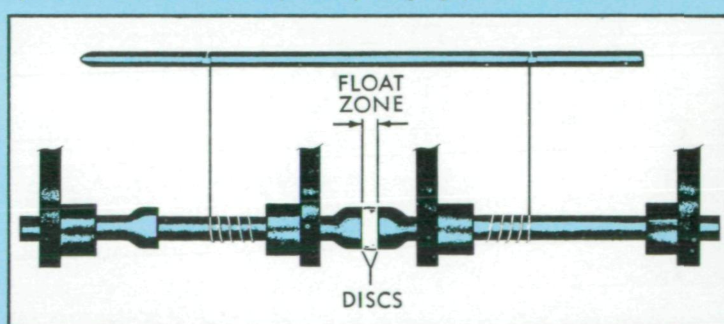


A sample consisted of a single crystal of the semiconductor indium antimonide (InSb) machined to cylindrical shape. Each sample was enclosed in a cylindrical capsule made of graphite with an enlarged cavity in one end.

In space: A drop of molten InSb formed on the heated end of the sample when the capsule was placed in an electric furnace. The drop was retained by surface tension and adhesion forces. Slowly lowering the temperature of the cavity around the melt caused the material to solidify reforming a single crystal. The crystal was expected to remain spherical during resolidification due to surface tension effects.

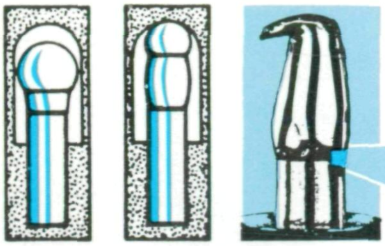
The Liquid Float Zone

A liquid cylinder was formed by placing a drop of liquid on each of two discs which were attached to rotatable rods. The discs were moved towards each other until the drops coalesced to form the "liquid float zone." The fluid maintained the shape of a stable cylinder across an unexpectedly large gap.

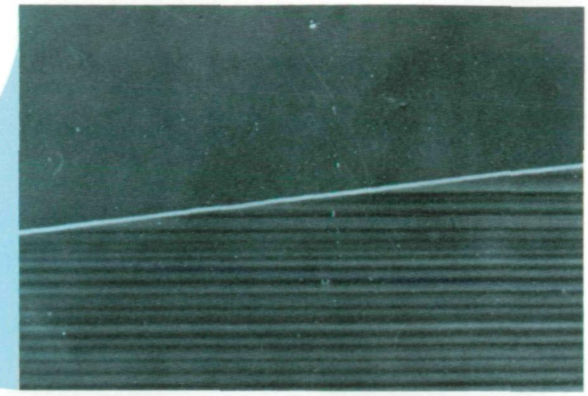


The stability of the zone was demonstrated when the discs were rotated in the same or opposite directions.

among important phenomena observed during the crystal in a way that is impossible on Earth.



Instead, the crystal elongated as it cooled until it hit the end of the chamber and bent over.

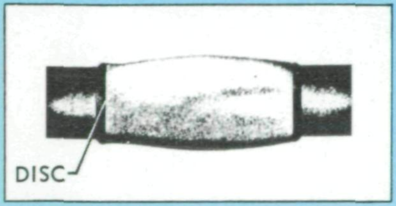


Cross section of the interface between the original crystal and the resolidified portion.

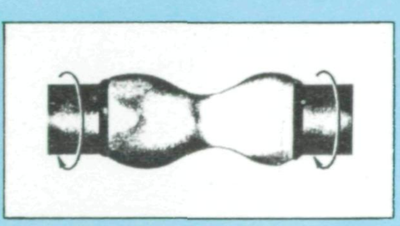
Different diffusions of impurities are illustrated. The Earth grown portion at the bottom contains striations caused by impurities of different density.

The material at the top, remelted and recrystalized in space, shows none of the striations present in the original material.

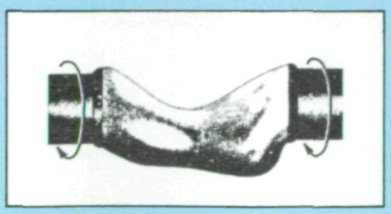
This Skylab experiment confirmed the prediction that longer liquid zones would be more stable in space than on Earth and showed what happens when rapid rotation destabilizes the liquid.



Liquid zone suspended between two nonrotating discs



Unstable liquid shape: rotating at 43 r/min



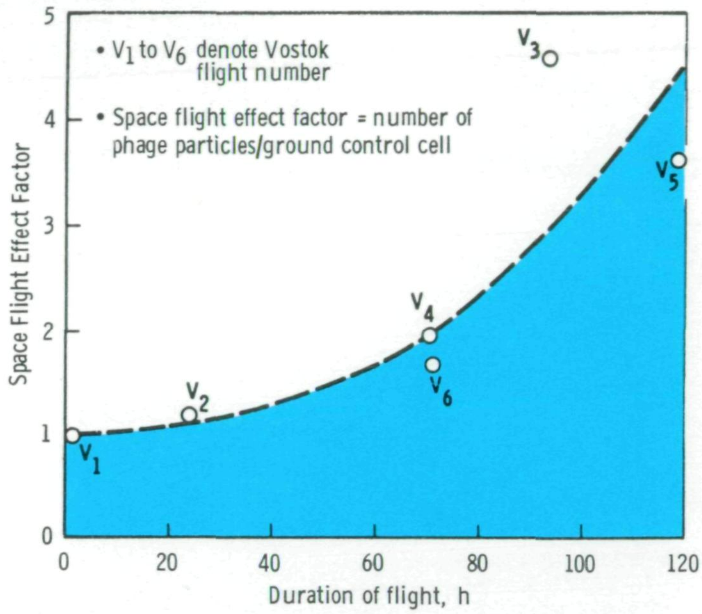
Unstable liquid shape: discs rotating at 60 r/min

The experiment also demonstrated that float-zone refining, a key process in manufacturing high grade electronics materials, can be done with little trouble in space.

BIOLOGICAL EFFECTS

MICROBIAL PROPAGATION RATES IN SPACE AND ON EARTH MAY BE DIFFERENT

- Increased growth rates of *Actinomycetes* and *Salmonella typhimurium* in space have been reported.
- Repeated experiments with *Escherichia coli* K-12 (λ) during Russian Vostok missions have shown increased phage production rates which vary with space flight duration.



RADIATION SENSITIVITY OF MICROBES MAY BE ALTERED IN SPACE

- Experiments onboard the Apollo 16 spacecraft have shown that T-7 coliphage and certain spores were more sensitive to the lethal effects of ultraviolet radiation during weightlessness.

SPORES OF BACILLUS SUBTILIS-168

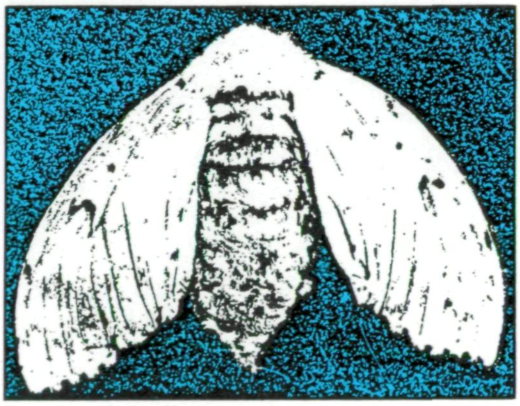
HIGHER ORGANISMS DEVELOPMENT AND PHYSIOLOGY ARE AFFECTED BY ORBITAL FLIGHT (Skylab, Biosatellites, and others)

- PLANTS
  - Changes in mitotic spindle mechanisms have been shown in microspores, megaspores, and root tip cells of *Tradescantia paludosa*
  - Wheat seedlings grown in space have shown increased respiration and increased peroxidase activity at the site of epinastic curvature
  - Skylab experiments demonstrated a variable and irregular phototropism in sprouting rice seeds. This indicates a distribution of growth hormones away from stem tips, probably due to zero gravity.

- INVERTEBRATES
  - The diapause (hibernation stage) of Gypsy Moth eggs was terminated after only one month of space flight. No method is available on Earth to shorten the normal 4 to 6 month diapause of Gypsy Moth eggs.

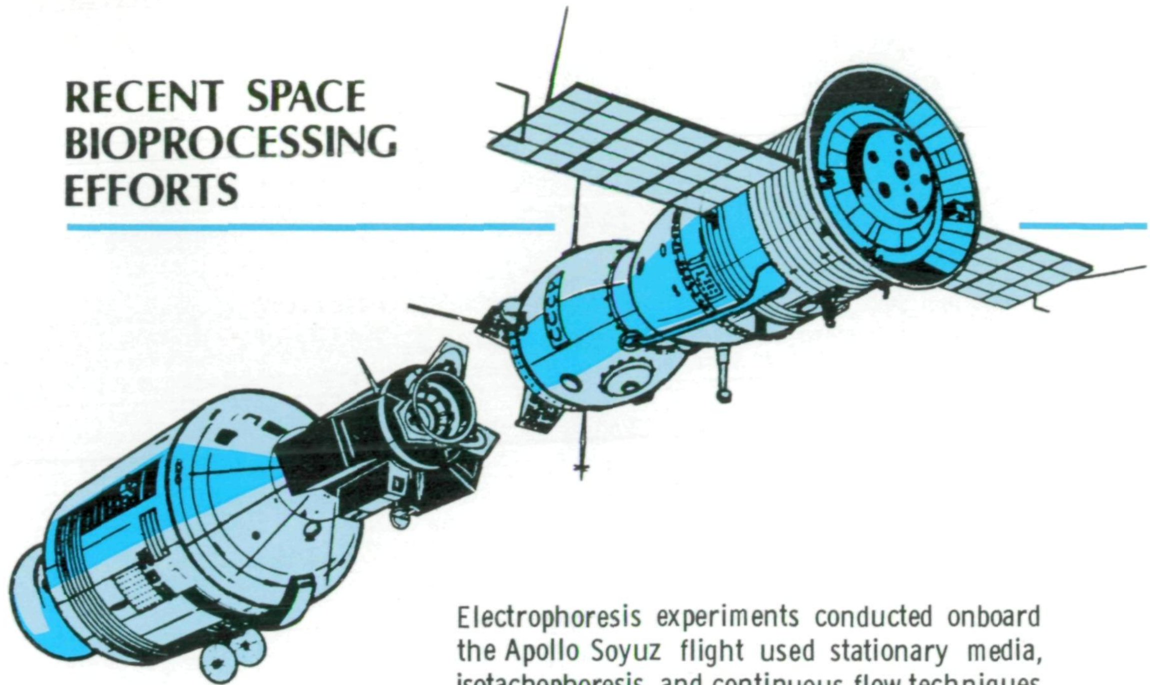
Adult Gypsy Moth hatched from an egg brought back after 84 days in space (Skylab)

Results stimulated new research approaches and hope for the possibility of practical control measures for this destructive pest



- VERTEBRATES
  - Microelectrode recordings from single fibers of the eighth cranial nerve in intact frogs have shown that the frequency of spontaneous nerve firings in vestibular sensors slowed during early exposure to weightlessness. Subsequent adaptation is illustrated by a slow return to the preflight frequency in approximately six days of spaceflight.

RECENT SPACE BIOPROCESSING EFFORTS



Electrophoresis experiments conducted onboard the Apollo Soyuz flight used stationary media, isotachophoresis, and continuous flow techniques to separate or isolate:

- mixtures of human and animal red blood cells
- B and T lymphocytes
- human kidney cells capable of producing urokinase
- bone marrow cells which produce red blood cells.

SOME ADVANTAGES OF NULL GRAVITY

Weightlessness provides better control of certain parameters in biological and biochemical manufacturing, e.g.,

- absence of convection and sedimentation
- more stable emulsions from immiscible fluids
- separation of materials difficult to isolate in one-g
- processing in liquid float zones without the use of a container
- mass transfer in liquids, wholly controlled by diffusion.

SOME POSSIBLE APPLICATIONS FOR BIOPROCESSING

SEPARATION

Electrophoresis, dialysis and other separation techniques may lead to ultra-purification of fragile biological substances, e.g.,

- specific cell types and mutants
- high density lipoproteins
- high purity erythropoietin
- factor VIII (antihemophilic factor)
- virus sub-unit vaccines
- sub-types of immunoglobulin G
- high purity biologicals uncontaminated by antigenic residues.

BIOSYNTHESIS

Zero-g fermentation and tissue culture may lead to new syntheses of biologicals which are impractical to produce on Earth, e.g.,

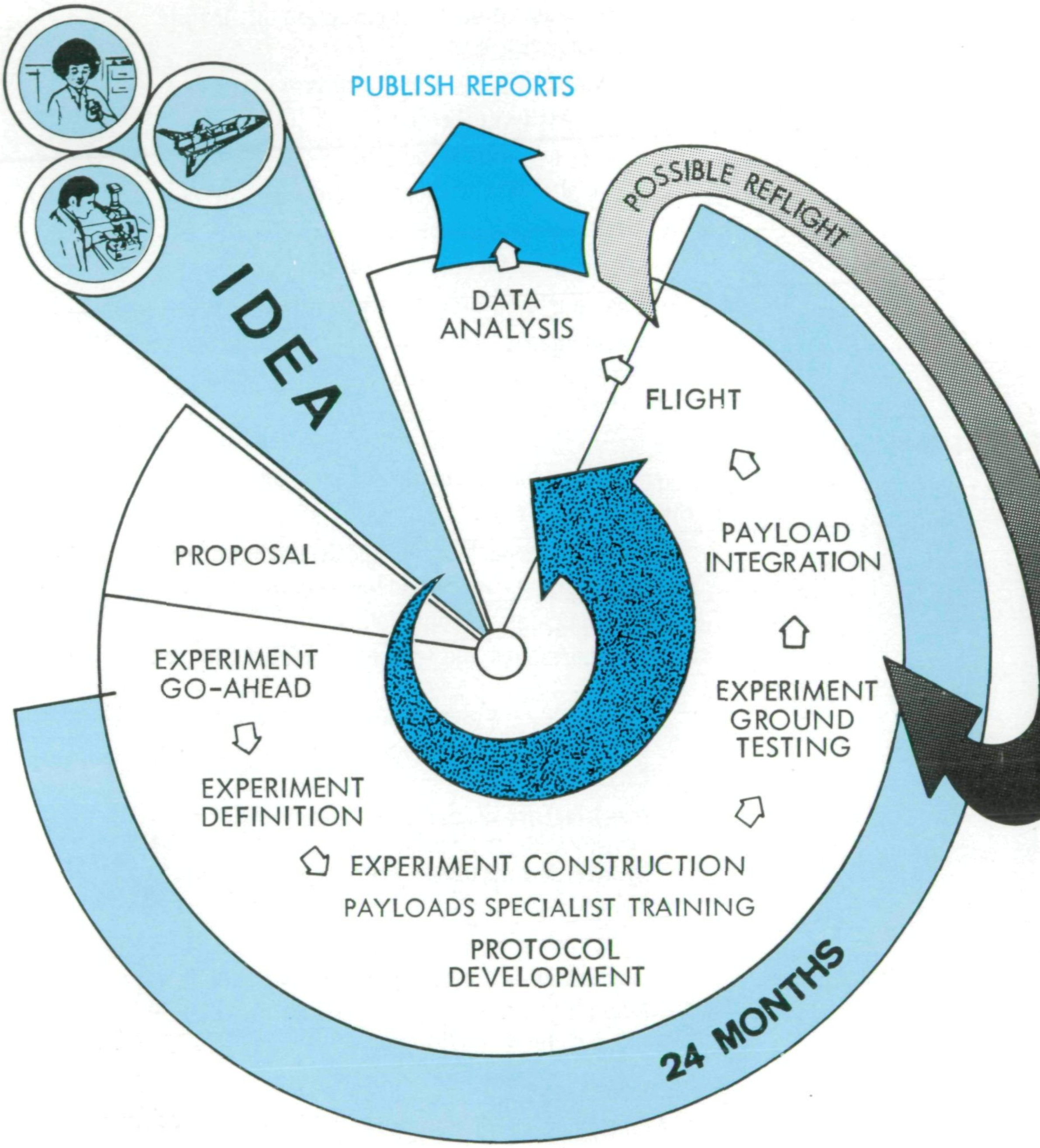
- medically important biologicals produced from hydrocarbons and other immiscible substrates
- new vaccines and antibiotics
- new hormones and enzymes from specific cell lines
- production of reactive intermediates which are required in the manufacture of certain biologicals on Earth
- manufacture of certain primary metabolites (amino acids, nucleotides, etc.) made possible by altered microbial feedback controls, due to zero-g.

BIOTECHNOLOGY

The production of new biocompatible materials from stable multiphasic systems, and the use of vacuum separation and other techniques could lead to

- polymer systems for artificial organs
- new composite materials for prosthetic devices
- implantable microcomputers and myoelectric control devices for artificial limb controls and physiological sensor systems.

Developing the Experiment



Do you have industrial manufacturing processes or research projects which are impractical because of heat convection, sedimentation, phase-density separation, or other gravity induced problems?

Are you interested in knowing more about materials behavior in space and space bioprocessing opportunities?

Studies will be conducted under the auspices of the National Aeronautics and Space Administration (NASA) to determine the feasibility of producing or processing certain biological materials in space. The involvement of the science community is requested for the planning of these studies.

A series of colloquium workshops and seminars are planned for the near future at the Lyndon B. Johnson Space Center. NASA will present space processing accomplishments and outline opportunities for research flights of the Spacelab beginning in 1980. Workshop-type discussions will be held to explore promising new biological research areas, industrial trends, and to help coordinate ideas from interested scientists.

Invitations to the scientific community to participate in "Planning the NASA Life Sciences Program in Space" and opportunities to participate in the "NASA Space Processing Sounding Rocket Program" have already been announced by NASA Headquarters. More information and copies of these announcements may be obtained by writing:

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Dennis R. Morrison, Ph.D./DF 2
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Houston, Texas 77058


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