U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC TECHNICAL REPORT 61-123

SMALL ROCKET LIFT DEVICE

Task 9R38-11-009-14

Contract DA 44-177-TC-642

November 1961

prepared by :

BELL AEROSYSTEMS COMPANY
Buffalo, New York

2464-60

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U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

Under the terms of Contract DA 44-177-TC-642, the Bell Aerosystems Company has been investigating the feasibility of utilizing small rocket units attached to a man's body to provide increased mobility through a limited flight capability. The investigation has been concerned primarily with determining the feasibility of man's performing controlled short-range low-altitude flights supported solely by rocket thrust. The feasibility of the concept was satisfactorily demonstrated during the course of the program.

The report presented in the following pages is the third report prepared under the over-all Small Rocket Lift Device program, and presents the results of static, tethered, and free-flight tests of the device. The first two reports, which are listed in the reference section of this report, describe the analytical and component-testing portions of the program. The conclusions contained herein are concurred in by the U. S. Army Transportation Research Command, Fort Eustis, Virginia, the cognizant agency for Contract DA 44-177-TC-642.

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SMALL ROCKET LIFT DEVICE
PHASE II
TESTING OF THE ASSEMBLED UNIT

Contract DA44-177-TC-642

July 1961

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U.S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

FOREWORD

For the past six months, manned rocket powered flight experiments have been directed toward proving the feasibility of such a concept. A program such as this requires excellent teamwork and dedicated efforts of many specialists. An experienced team made up of just such people has been formed and through the various contributions of knowledge, advice, and time of the individuals involved, the concept has been successfully proven.

The U. S. Army Transportation Research Command has assigned Mr. Robert Graham as Project Officer; his understanding help and advice have been of great value. Mr. Wendell Moore serves as Technical Director for Bell Aerosystems Company. Acknowledgment is made of the overall systems design and coordination efforts of Mr. E. Ganczak, which have been a large factor in producing the success achieved. Mr. H. Graham served as test engineer and flight operator. It was through his courage and good engineering analysis during the flight test program that a large portion of this success was accomplished. Mr. E. Kreutinger served as crew-chief during the entire program. His experience and know-how were invaluable during the safe and successful development of the rocket belt. F. Tyler Kelly, M. D., religiously attended each flight and provided several important design suggestions. Mr. J. Burgess served as a human factors engineer and very thoroughly documented the results of the flight tests. Mr. J. Kroll served as stability and control engineer, and his efforts contributed a great deal to the successful control system.

Phase II of the SRLD Program was initiated 10 November 1960 and was concluded successfully with a demonstration on 25 May 1961.

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ILLUSTRATIONS (CONT)

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LIST OF SYMBOLS

Symbol	Unit	
b_3	lb/ft/sec	artificial damping applied to stabilizer-mass
b_N	ft-lb/rad/sec	damping of control nozzle
BT	°F	insulation barrier temperature (cold side, left ring attachment)
C*	ft/sec	characteristic exhaust velocity
d_3	ft	distance from stabilizer mass to nozzle gimbal
EXT	°F	exhaust temperature (3 feet from nozzle)
F	lb	thrust
F_{corr}	lb	thrust (corrected to 410 psig feed line pressure)
FLP	psig	feed line pressure
FLT	°F	feed line temperature
GGP	psig	gas generator pressure (corrected to 410 psig feed line pressure)
GGT	°F	gas generator temperature
G_1, G_2		slopes of thrust with throttle valve position (see figure 21)
I_N	slug-ft^2	moment of inertia of nozzle about gimbal axis
I_{sp}	sec	specific impulse
I_1	slug-ft^2	moment of inertia of upper torso about hip socket

LIST OF SYMBOLS (CONT)

Symbol	Unit	
RNP	psig	right nozzle pressure
RNT	°F	right nozzle temperature
TP	psig	tank pressure
T_R, T	lb	total thrust
T_{s_1}	°F	tube skin temperature (6 inch from gas generator)
T_{s_2}	°F	tube skin temperature (at tube bend)
T_{s_3}	°F	tube skin temperature (3 inch from nozzle)
W	lb/sec	weight flow
W_t	lb	total weight
W_{corr}	lb/sec	weight flow (corrected to 410 psig feed line pressure)
W_S	rad/sec	natural frequency of stability augmentation
X	ft	lateral displacement
y	ft	vertical displacement
g	ft/sec^2	gravitational acceleration
x	inches	display lateral displacement
δ_p	psi	differential pressure
δ_c	degree	manual control deflection

LIST OF SYMBOLS (CONT)

Symbol	Unit	
δ_s	degree	stability augmentation system control deflection
ζ	ft-lb/rad^2/sec^2	damping ratio of stability augmentation system
ω_n	rad/sec	undamped natural frequency of stability augmentation system
I_2	slug-ft^2	moment of inertia or lower torso about hip socket
K	lb/ft	ground contact spring constant
K_1	ft-lb/rad	hip spring constant
K_N	ft-lb/rad	stiffness of control nozzle
K_8	lb/ft	spring constant of stabilizer spring
LNP	psig	left nozzle pressure
LNT	°F	left nozzle temperature
LP	psig	line pressure
M	ft-lb	rolling moment
l_1	ft	distance from nozzle gimbal axis to upper torso center of gravity
l_2	ft	distance from upper torso center of gravity to hip socket
l_3	ft	distance from lower torso center of gravity to hip socket
l_5	ft	distance from body centerline to stabilizer mass

LIST OF SYMBOLS (CONT)

Symbol	Unit	
m	slugs	total mass
m_1	slugs	mass of upper torso
m_2	slugs	mass of lower torso
m_3	slugs	stabilizer mass
n_1, n_2		throttle valve positions defined in Figure 21
P_cAbs Corr		chamber pressure (corrected to absolute)
PFT	°F	propellant feed temperature
q_1	degree	roll angle of upper torso (above hip socket)
q_2	degree	roll angle of lower torso (below hip socket)
δn	degree	nozzle deflection
θ	degree	stick deflection
$\vert\theta\vert$		stick deflection in percent of maximum position
ξ		throttle valve position - percent of maximum condition
$(\ddot{\ })$	double dot (e.g. $\ddot{x} = \frac{d^2\delta}{dt^2}$	denotes second derivative

NOTE: Many symbols appearing in this list are not used in this report but have been used in previous reports issued in conjunction with this project and are included here for reference purposes.

SUMMARY

In answer to a generalized requirement for increased mobility of the foot soldier, an approach has been conceived wherein small rocket units are attached directly to an individual to provide him with short flight capability.

The U. S. Army Transportation Research Command (TRECOM) awarded Aerojet-General Corporation a study contract to investigate the theoretical feasibility of such devices. This resulted in a report (Ref. 1) which concluded that the concept was feasible.

To substantiate the theoretical investigations and captive flight tests utilizing nitrogen gas, it was deemed necessary to build a manned free-flight feasibility model of such a device and flight test it. Toward this end, Bell Aerosystems Company was awarded Contract No. DA-44-177-TC-642 to perform this task under the direction of the U. S. Army Transportation Research Command (TRECOM), Fort Eustis, Virginia.

The Contract Work Statement for this task was divided into two distinct phases. Phase I required the design, fabrication, component testing, and assembly of the Small Rocket Lift Device, followed by an engineering report of this work. Phase II required static test firings of the assembled unit, tethered and free-flight testing with a human operator to determine the over-all feasibility, performance, safety, and utility of such a device, with adjustments and modifications as required to achieve satisfactory operation. This engineering report along with a documentary movie constitute a record of the work accomplished in Phase II.

The design of the SRLD is fundamentally a pressurized hydrogen peroxide rocket propulsion system mounted on a molded Fiberglas corset shaped to fit the body of the operator. Arm lift rings are attached to the corset through a central pivot point at the back of the operator's neck. Two handles attached to the rings extend forward for control purposes. Actual lift is provided by two rocket nozzles, one mounted on each side of the operator above the arms and above the center of gravity. The nozzles are fed by a central gas generator controlled by a motorcycle type throttle at the operator's right hand. Figure 1 is a photo of the actual SRLD.

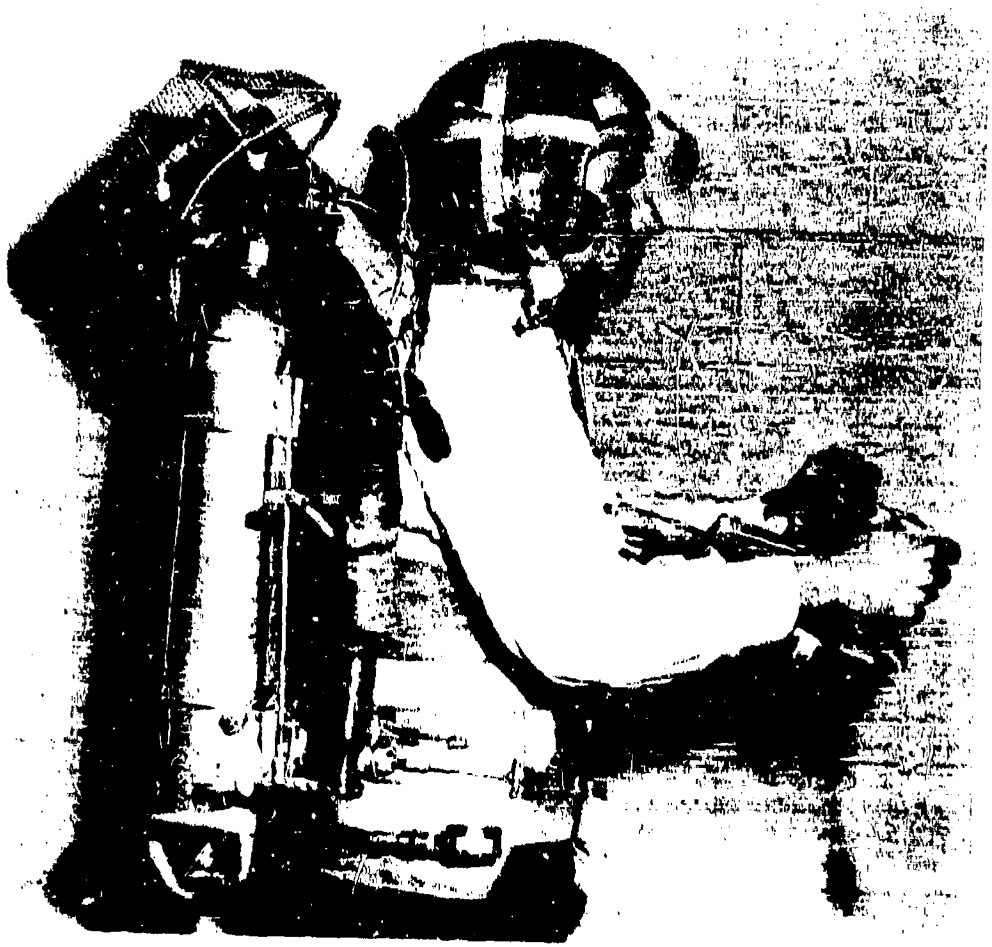


Figure 1. SRLD and Operator – Right Side View

After successful hot firings with a plaster dummy in the test cell, the SRLD was flown in manned tethered flights. Numerous changes were made to the control system during the tethered flight program. Until a relatively stable and controllable man-machine combination was developed, the most difficult problem was developing an acceptable yaw mechanism. Fifty-six tethered flights were made.

The first free flight was accomplished 20 April 1961. It resulted in a successful 100-foot translation with the operator landing on the target. Subsequent free-flight testing demonstrated reliability, safety, and controllability through many types of maneuvers, such as hovering, hill-climbing, coordinated turns, translation with pivot turns, and return to take-off point, flights over obstacles, etc.

The propulsion system proved 100% reliable and is still operating satisfactorily after 95 runs with an accumulated running time of 36.9 minutes. The free-flight program was concluded with a demonstration at the end of 28 flights, at which time it was considered by all concerned that the feasibility of this concept was satisfactorily demonstrated.

An abbreviated operations analysis was accomplished. This indicated that the greatest need would be for translation types of flying for such missions as crossing rivers, climbing hills, and flying over otherwise inaccessible terrain.

Several items remain to be researched further, before sufficient criteria can be established for the design of prototype models. These are the establishment of quantitative flight performance data, improvement of the yaw control mechanism, and flight time remaining indicator, as well as the addition of a safety device such as a parachute or paraglider which could also be utilized for range extension.

CONCLUSIONS

The concept of attaching a rocket propulsion system to a man for the purpose of transporting him from one place to another has been successfully demonstrated. This was done by means of rigorous static testing of the propulsion system, a manned tethered flight program during which various improvements were incorporated, and finally by a manned free-flight program consisting of various types of maneuvers. Additional quantitative data on stability and control is needed to intelligently establish prototype specifications. Hydrogen peroxide, although very successfully utilized on this program, would have a limited tactical use due to its handling characteristics and limitations at low ambient temperatures. A better tactical propellant must be found. The basic concept of distributing the SRLD static weight around the man's body by means of a padded Fiberglas corset proved highly successful. The flight test program revealed that lifting a man under the arms for a short period of time had no deleterious effects and permits excellent kinesthetic control.

RECOMMENDATIONS

As a result of the Phase II flight test program of the SRLD the following recommendations are made. Additional work should be accomplished to gather further data for the purpose of establishing prototype specifications. Specifically the following items should be accomplished.

(1) Perform additional flight testing with instrumentation to gain quantitative stability and control data.

(2) Design and test an improved flight time remaining indicator suitable for prototype use.

(3) Perform configuration and performance improvement studies.

(4) Design, fabricate, and test a parachute, paraglider, or like device for enhancing the safety of operation and increasing the range.

(5) Perform stability and control studies as a result of item (1) to further the state-of-the-art of the man-machine mathematical models required for SRLD prototype system design.

(6) Establish the required program for training flight operators.

(7) Perform operations analysis to establish the desirable performance characteristics for tactical use.

(8) Perform operational propellant studies in an effort to define the requirements for a tactically suitable SRLD propellant.

In view of the remarkable success in demonstrating the feasibility of this concept, it is recommended that further development of this system be prosecuted vigorously.

I. SYSTEMS DESIGN

After conclusion of the SRLD final assembly, the system water-flow tests were performed successfully. This ended Phase I of the experimental portion of the feasibility program and a report, Reference 1, was prepared. On 10 November 1961 the go ahead was received from TRECOM for the Phase II portion of the work statement.

Phase II began with hot-firings of the SRLD mounted on a plaster dummy in a rocket test cell. Two vertical guide cables were installed from floor to ceiling through the dummy and the throttle control was extended with a flexible cable to permit manual firing of the SRLD from outside the cell. This permitted pilot familiarization with propulsion system control. During these tests the SRLD was accidently dropped to the support pad several times from heights as much as three feet with no adverse effects on the structure. After the completion of eleven tests, the SRLD was considered safe and reliable enough to proceed with manned tethored flights. During the course of these tests it was determined that the throttle valve was sticking and not opening and closing properly. This was caused by the shutoff O-ring coming out of its groove during flow conditions. The O-ring was subsequently completely removed. Detailed information on this series of tests is included as Appendix IV.

An indoor test site was chosen for the initial tethored flights. This permitted applying vertical and horizontal grid lines to the wall of a room against which the flight operator could be photographed for purposes of determining rates of translation, body and limb angles as well as altitude control. Two horizontal cables were installed in the building, one at the floor and one at the ceiling, upon which upper and lower tether lines could travel by means of pulleys. The first two tie-down tests were accomplished at this site.

A special flight suit was designed and fabricated for use in the presence of 90% hydrogen peroxide. The suit was designed to draw the sleeves and legs tightly about the operator's limbs for the purpose of readily defining body and limb positions and angles. A picture of this suit is shown in Figure 2. A heavy duty eyelet was inserted at the crotch for a lower tether attachment point.

Figure 2. Special Flight Suit

The first tethered flight was accomplished by operator Moore on 29 December 1960. Several things were immediately apparent. One was that the building itself was much too small for this type of test. Secondly, the lower tie-down cable proved to be more of a hindrance than a safety measure. When the operator would get so much as a foot or two off center, it would have the effect of tipping him. This site was abandoned after the second test, when the operator received a slight knee injury from hitting the wall.

Subsequently, two thirty-foot-high towers were set up outdoors with a horizontal cable running between the tops. On this horizontal cable a riding pulley with a safety line attached was installed. No lower tether was used from this point on. The outdoors location provided a considerable improvement in the flight test results. However, low temperatures began to prevail in the Buffalo area. These temperatures resulted in exhaust steam condensing into vapor clouds which obscured both the operator's view and the tether man's view of the operator in flight. During one such flight the operator landed slightly off balance backwards and fell to the pavement in a seated position. This resulted in a slight fitting leak near the bottom of the tanks. A tank guard made of soft aluminum tubing was then installed to prevent damage in the future. This tank guard is depicted in Figure 3. During this series of tests, the squeeze type throttle handle was being evaluated. It proved to be a poor design for the type of precise throttling required. As a result, a rotary type motorcycle throttle handle was installed in an upright position on the SRLD instead of the downward position of the squeeze-type throttle. Figure 4 is a photo of this installation. This was first used on tethered flight No. 5. No return spring was incorporated into the design.

Beginning with tethered flight No. 5, the SRLD was flown inside the large Bell experimental flight hangar, where unrestricted indoor room became available. Figure 5 is an in-flight photo in the hangar. The modified motorcycle throttle provided a tremendous improvement in controllability. Beginning with flight No. 7 the gimballed nozzle assembly was locked in the pitch and lateral directions and utilized through the hand controller for yaw control only. No centering mechanism was provided. This again proved a small step forward as the gimballed nozzles appeared to be much too sensitive for the type of control required. Coupled with this change the radial pivot bearing at the back of the neck which supports the nozzle and gas generator was changed to a spherical rod-end type of bearing. This permitted both lateral and pitch control of the nozzles by up or

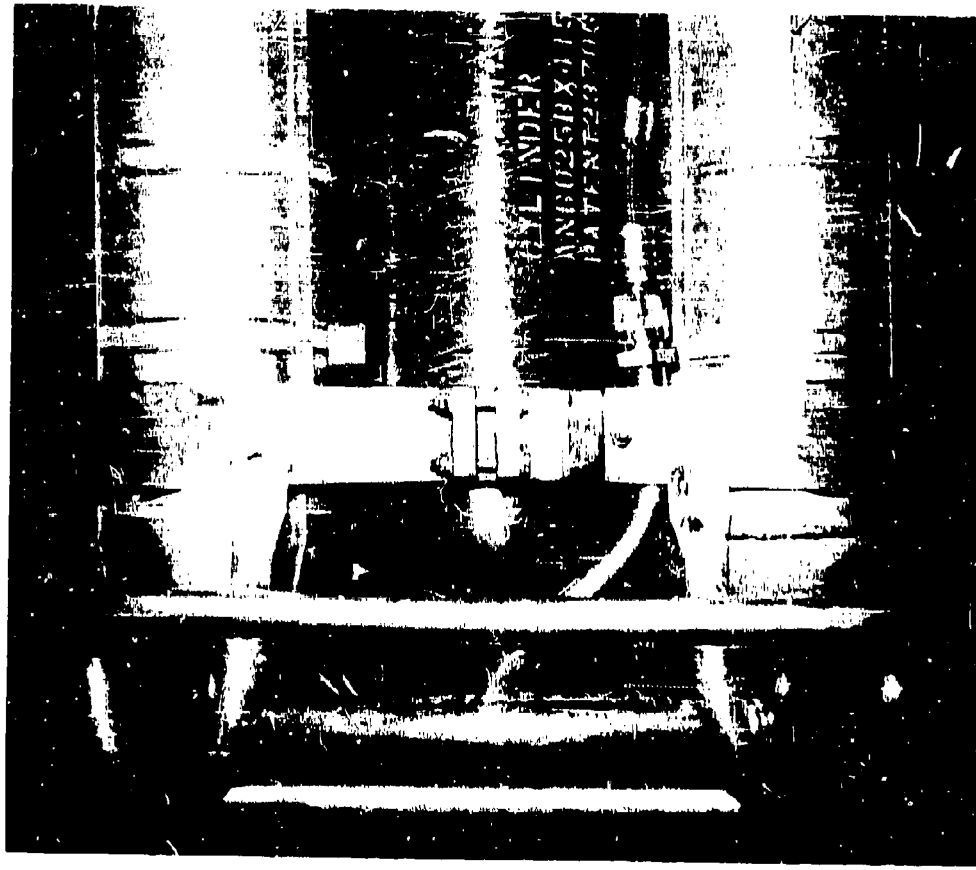


Figure 3. Tank Guard Installation

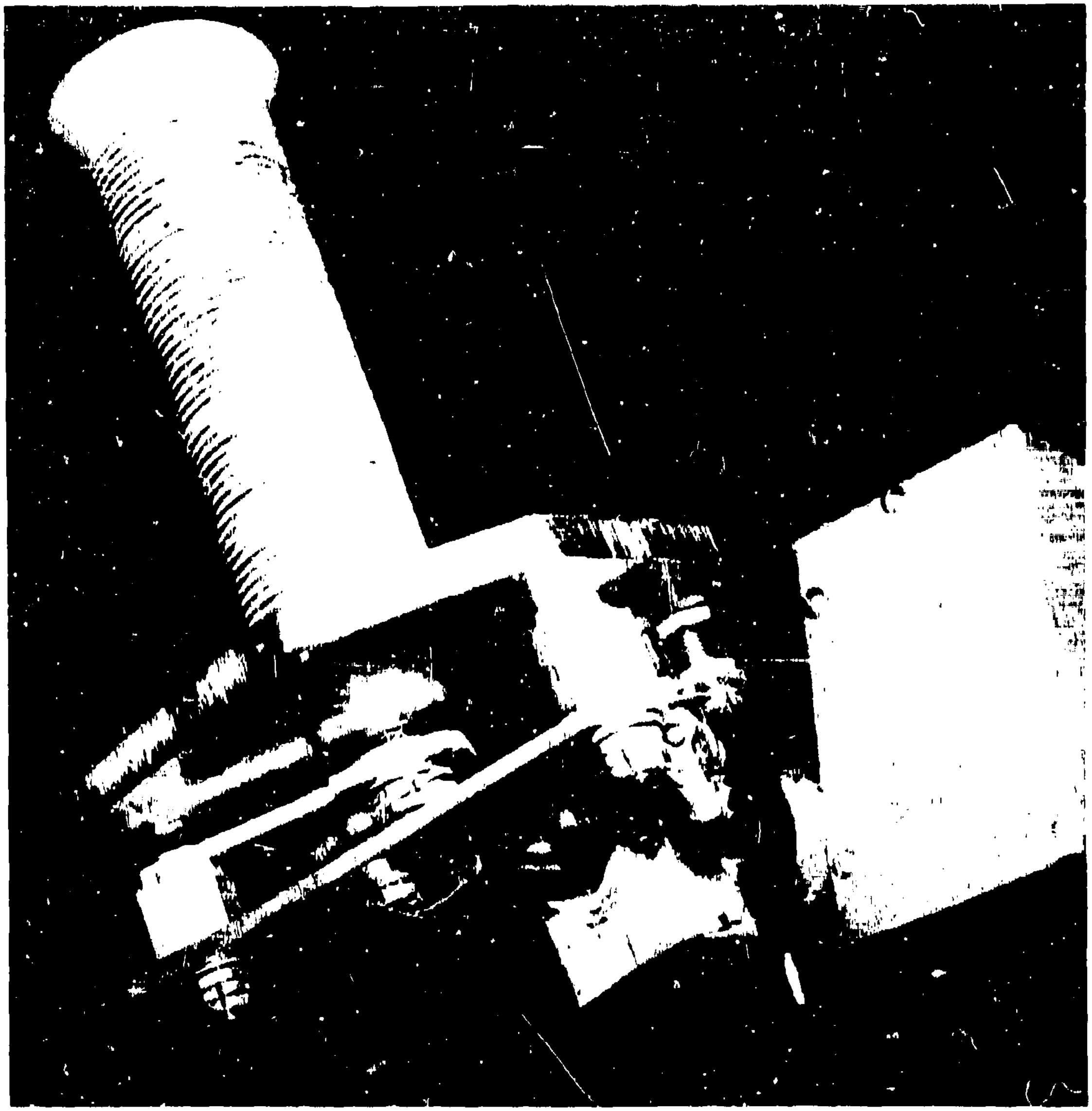


Figure 4. Rotary Type Throttle Control Handle

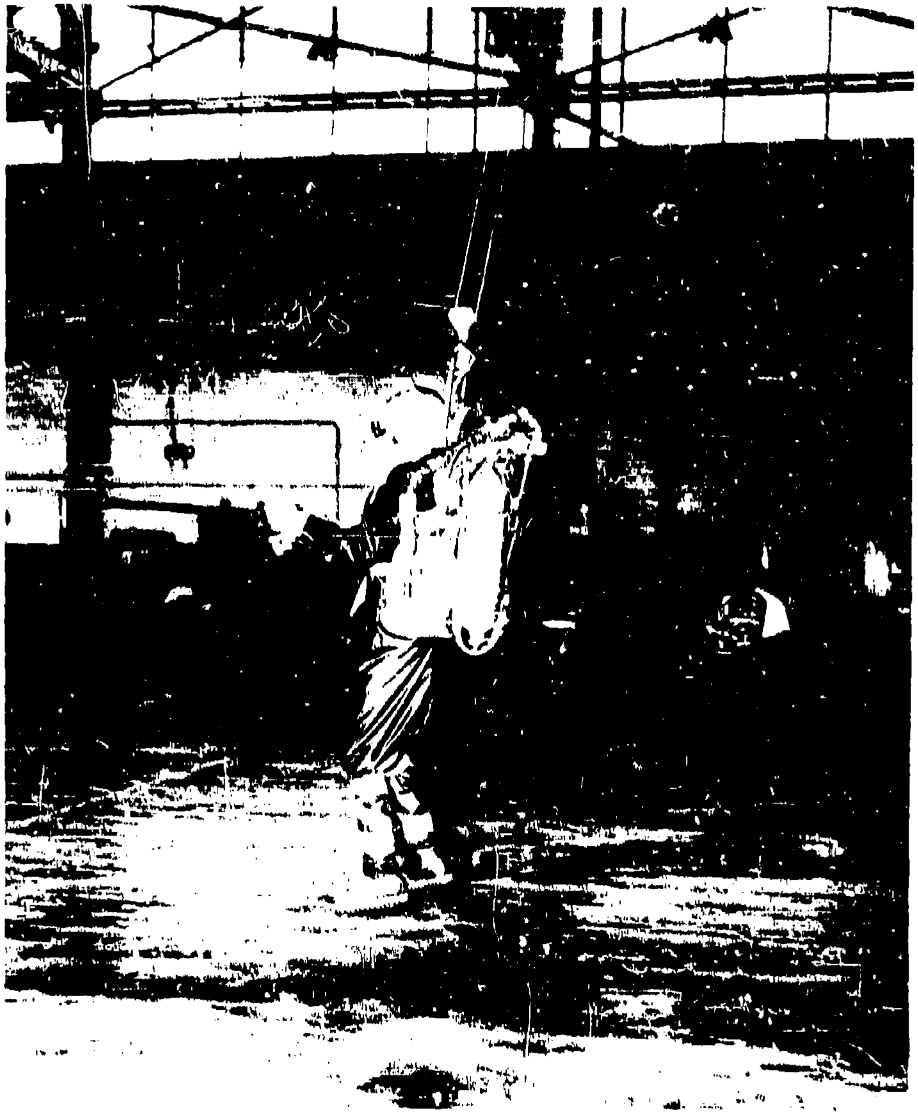


Figure 5. Tethered Flight Inside Hangar

down movement of the handles. This again proved to be a great help in the control of the SRLD. During this period it was also noticed that the nozzle exhaust streams were interfering with the legs and feet of the operator, causing lateral disturbances of the man-machine combination. As a result of this, both exhaust nozzles were canted 5 degrees outward from the vertical centerline. This change provided another improvement in the flight control of the SRLD.

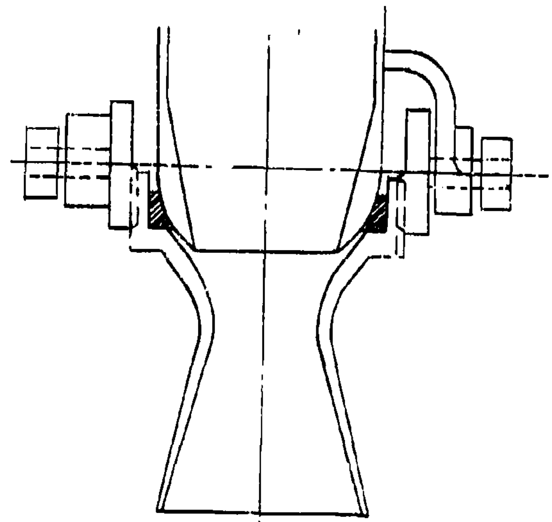
On February 17, 1961, during a hovering test (Flight 20), an accident occurred in which operator Moore became entangled in the safety rope which subsequently cut, dropping the operator to the floor, causing a knee injury. As a result of this flight, a screen guard was placed over the throttle valve, the safety tether was changed from woven plastic rope to cable and a return spring was installed on the throttle valve. Additional crash padding was also added around the quick release latches on each side of the support rings.

Insomuch as we had designed and fabricated workable gimballed nozzles for the SRLD, it was decided to test them for control in all planes. The pivot bearing was then locked at the back and the gimballed nozzles were actuated in all planes by the left-hand control stick. The results of this change were not encouraging, fundamentally, because the nozzles were very difficult to align perfectly in neutral after being actuated in one direction or another, and control friction was undesirably high. They were also much too sensitive. As a result of this experiment, the gimballed nozzles were removed.

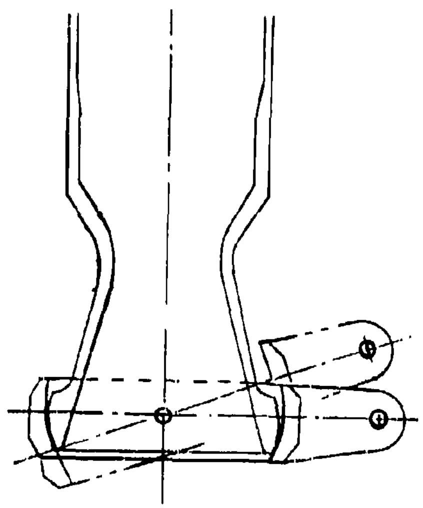
Rigid nozzles with jetavators for yaw control were then installed. This change is depicted in Figure 6.

Beginning with Flight 21, operator Harold Graham began training for the continuation of the SRLD flight tests. During the ensuing period, several additional changes were made in the SRLD. These included a larger abdominal support plate and the addition of a lower safety belt, as well as enlarged arm padding on the lift rings.

After 36 tethered flights and a total of less than fifteen minutes of flight time by operator Graham, it was decided that his proficiency and the improved control system of the SRLD would permit free flight.



a. Gimballed Nozzle



b. Jetavator Design

Figure 6. Nozzle Designs Tested

On the morning of April 20, 1961, the first free flight took place. A 100-foot strip was marked on the grass of the Niagara Falls Airport with a target at each end. The operator took off, flew a very straight path for a 100-foot distance, and landed on the target. Figure 7 is a picture of the actual flight path. Again on this flight a vapor cloud appeared due to the low ambient temperature; however, the flight was deemed completely successful and indicated that a considerable number of control problems were actually due to the tether rope assembly. During the ensuing free-flight program, several changes and improvements were made to the SRLD. A detent was added to the throttle control handle in such a manner as to provide a high momentary torque when reducing the throttle beyond the 70% mark. This was done after the operator accidently cut the rockets on several occasions during landings. Figure 8 depicts the torque required to actuate the throttle handle as it exists at the present time. This proved to be a most satisfactory safety change. When yaw control problems developed during flight, a centering spring device was installed on the jetavator control. This provided a definite feel for the pilot when returning from an actuated position either side of center, and provided much better yaw control during flight. Figure 9 is a graph of the static torque required to actuate the jetavators through full travel.

Various small additions and deletions were made to the operator's flight gear as well as the SRLD during the free-flight program. As a result, a revised over-all weight statement is provided in Figure 10.

No changes were required to be made to the propulsion system at any time during the Phase II flight-test program. It operated with an observed reliability of 100%.

The propellant warning indication system was revised several times during the free-flight program. The audio signal in the helmet was increased in intensity and frequency several times, but still could not be heard by the operator. A small internal earphone was tried, with negative results. The red warning light proved ineffectual in bright daylight and was removed. Finally, a small vibrator, actuated by the original timing circuit, was installed as a bone conduction device inside the helmet against the operator's skull. This proved to be a very effective signal and the operator's confidence improved markedly.

Figure 7. Operator's Flight Path – First Free Flight

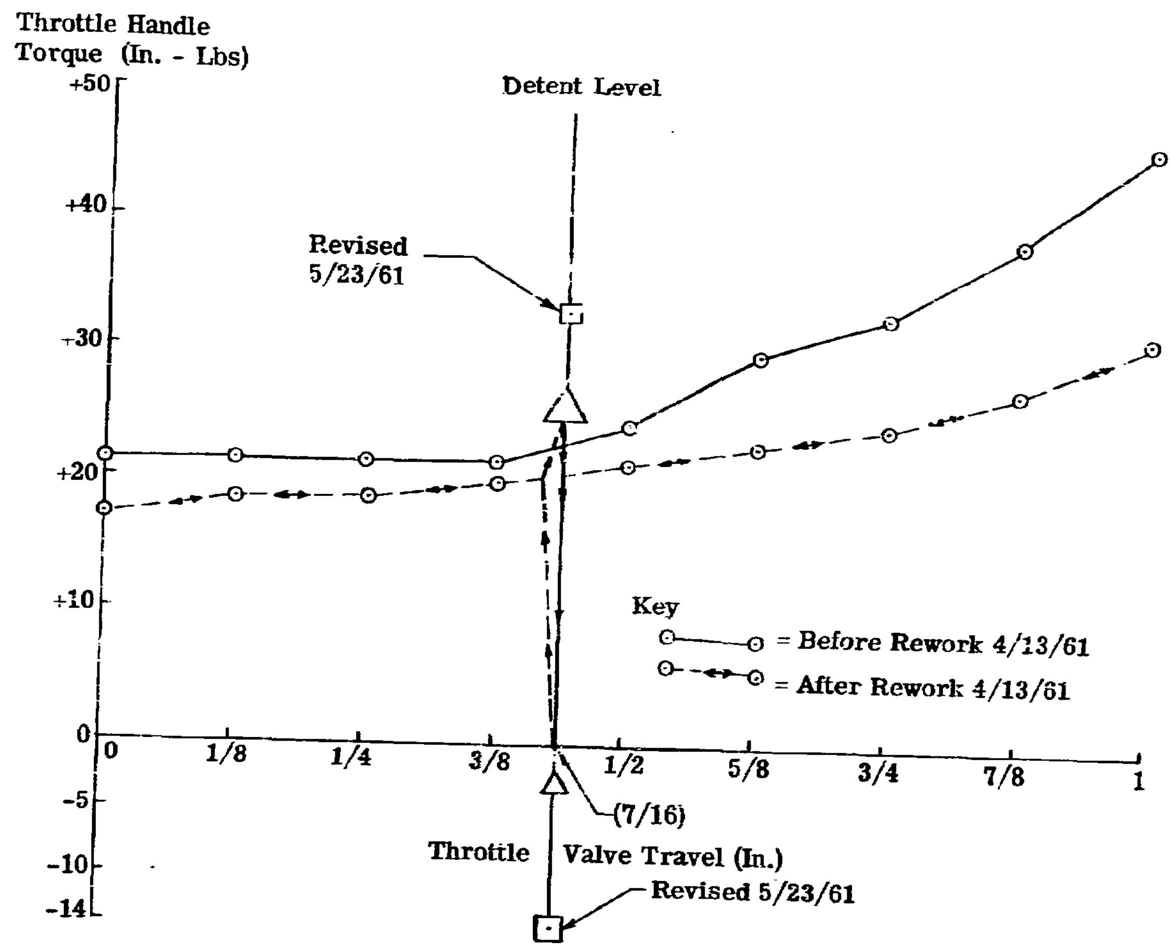


Figure 8. Throttle Handle Torque vs. Throttle Valve Travel

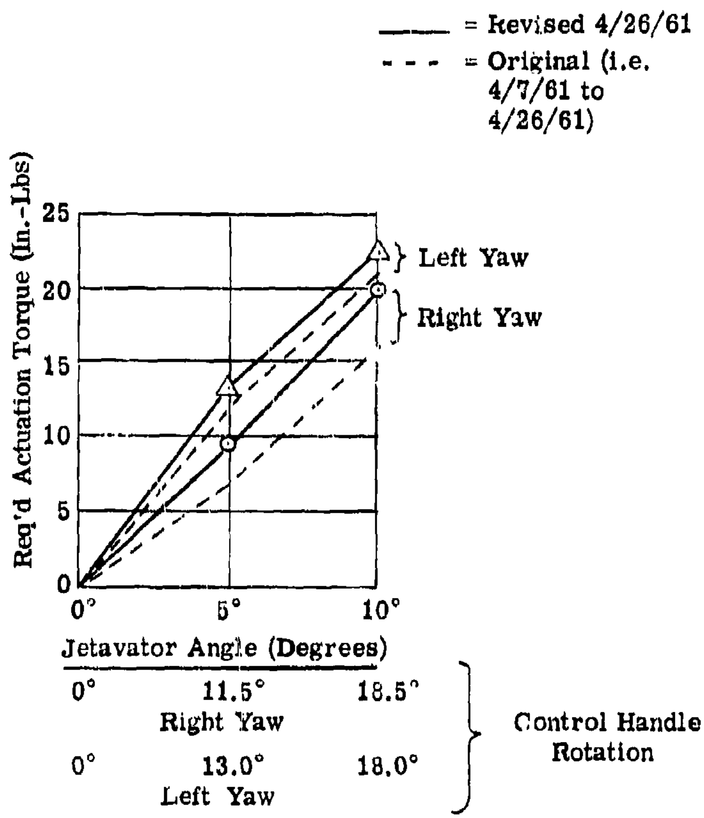


Figure 9. Required Actuation Torque vs Jetavator Deflection

OPERATOR, CLOTHING, AND PROTECTIVE GEAR

		Weight (Pound)
(1)	Operator (Stripped)	160
(2)	Flight Boots	4.55
(3)	Rubber Suit Top	2.15
(4)	Rubber Suit Bottom	2.00
(5)	Thermal Underware (Long, Tops and Bottoms)	1.55
(6)	Knee Guards (2)	1.35
(7)	Elbow Guards (2)	.80
(8)	"Nose" Guard	.40
(9)	Knee Padding (2)	.25
(10)	Pant Leg Straps	.25
(11)	Rubber Gloves	.15
	Total Operator and Apparel Weight	173.45
	Loadable Items	
	H_2O_2	48.0
	N_2	2.4
		50.4
	Total	
	Operator and Apparel	173.45
	"Dry" SRLD	78.0
	Loadable Items	50.4
	Gross Weight at Liftoff	301.85

Figure 10. Over-all Weight Statement (Sheet 1 of 2)

DRY SRLD

		Weight (Pound)
(1)	Gas Generator Assembly (Throttle valve inlet to jetavators less tether guard)	17.00
(2)	N_2Bottle (Including adapter and 8-inch connecting line)	16.00
(3)	H_2O_2 Tank Assembly (Including manifolding, flex line, bleed lines, and valves)	13.00
(4)	SRLD "H" Frame (Including valves, gages, and plumbing)	10.55
(5)	Right Arm (Including throttle control and cable, timer box and wiring, and padding)	5.15
(6)	Left Arm (Including yaw control and control cables and padding)	4.75
(7)	Helmet (Including vibrator and wiring	2.35
(8)	Fiberglas Corset (Including padding)	3.85
(9)	Abdominal Plate (Including attachment belts (2))	1.95
(10)	Dry Cell Battery	1.35
(11)	Tank Bottom Guard	0.70
	Total "Dry SRLD" Weight	76.65
	Total Actual	78.00

Figure 10. Over-all Weight Statement (Sheet 2 of 2)

During the free-flight portion of the program, records were kept on propellant remaining after each flight. This was done by draining and weighing the residual propellant. Figure 11 is a plot of propellant remaining vs gas generator firing time. The effect of higher flight velocity is not apparent from information presented in Figure 11. It is an obvious fact that an increase in velocity will result in an increase in distance travelled in a given period of time. It may not be quite as obvious that the rate of fuel consumption will be relatively unaffected by variation of velocity in the range visualized for the SRLD.

The over-all SRLD system was successfully free-flight tested through the following flight plans:

1. Forward translation (368 feet)
2. Translation, hover, and let-down
3. Hill climbs
4. Let-downs from hilltop
5. Creek crossing
6. Take-off forward translation, 180 degrees rotation and return to starting point
7. 180 degrees coordinated turns around a 100-foot semicircle
8. The slalom
9. Flight over 7-foot obstacle (firetruck)

Figures 12 through 15 were photos taken during some of the foregoing flight tests.

At the conclusion of 28 free flights, the SRLD system was considered to have demonstrated feasibility in a satisfactory manner and development flight testing was concluded on May 25, 1961.

Several important items remain to be tested and developed before sufficient data can be accumulated to properly design and evaluate prototype models. Quantitative data must be obtained on the in-flight performance. The yaw control system needs improvement. A direct reading propellant quantity system and a device for emergency let-down would greatly enhance the operational safety of the SRLD. Although hydrogen peroxide proved to be a very convenient and reliable propellant for feasibility purposes, its tactical use would be definitely limited by both the handling characteristics and the effects of low ambient temperatures. A more suitable tactical propellant should be developed for the SRLD.

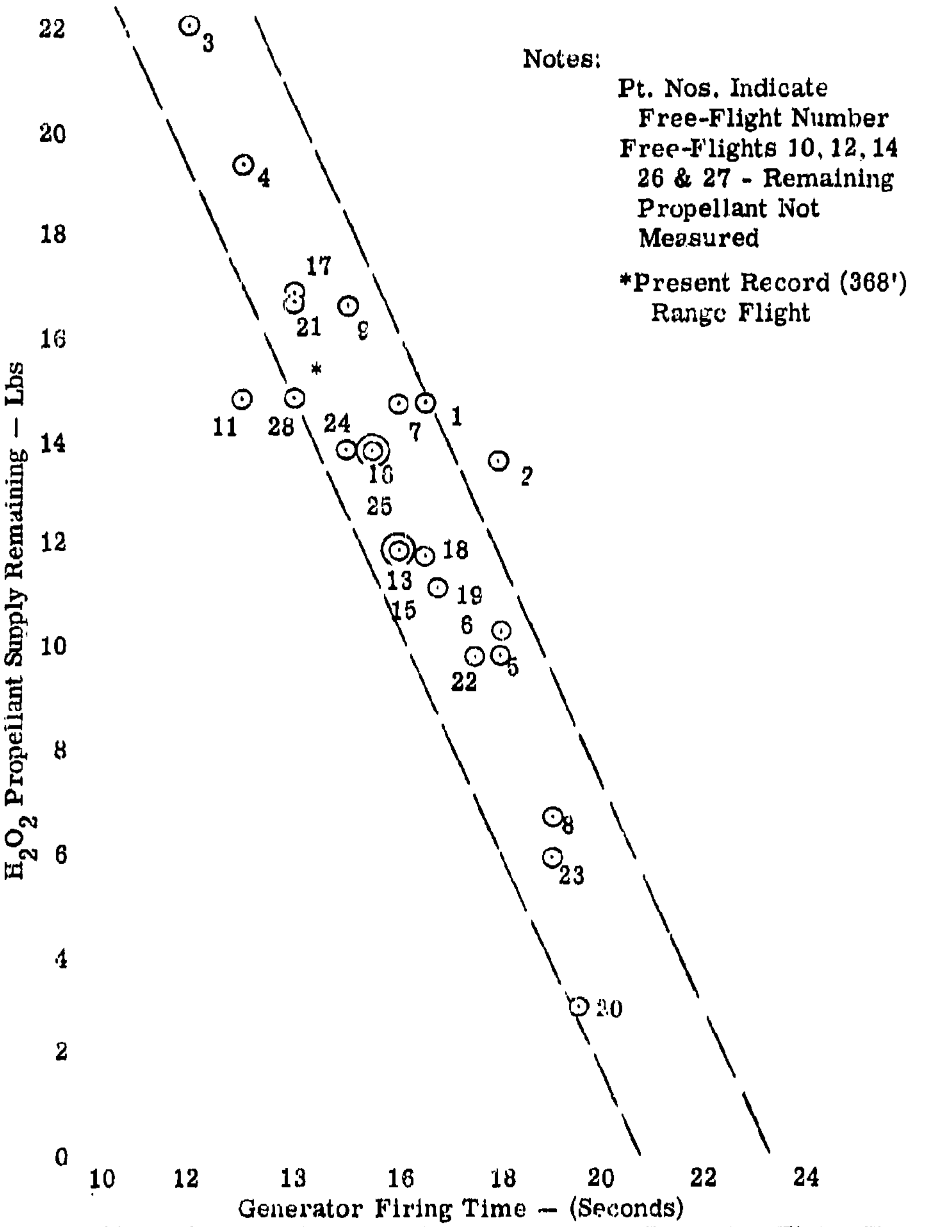


Figure 11. H_2O_2 Propellant Supply Remaining vs. Generator Firing Time

Figure 12. Going Around Turn

Figure 13. Climbing the Hill

Figure 14. Crossing the Creek

Figure 15. Flying Over Obstacles

II. PROPULSION SYSTEM

The SRLD propulsion system proved to be an extremely safe, reliable, and trouble-free design. Details of the system were described in reference 2. During the entire Phase II program, the only difficulty encountered was minor external nitrogen leakage due to O-ring wear in the Pressurizing and Vent valve (8123-472-015). This O-ring was changed on three occasions. The third time a harder synthetic rubber was used and no trouble has occured since its installation after Flight No. 81.

After 77 fillings of the hydrogen peroxide system, including numerous flights, when it was exposed to dust, dirt, etc., the system was checked for compatibility and found to be tolerable but nearing the acceptable limit. At this time it was dismantled, proof pressure tested, and reconditioned for service. Figure 16 is a graph of a gas evolution operation.

During Phase II, the second reworked H_2O_2 throttle valve was received and thoroughly tested. Flow characteristics of the final design were established and are presented in Figure 17. The valve was satisfactorily cycled 500 times with pressurized distilled water. The final leakage under pressure in the closed position was less than 3 cc/min. All other requirements were satisfactorily met.

The original catalyst bed, installed prior to the first hot firing of the gas generator, is still installed and performing satisfactorily. As of this writing, it has accumulated a total of 199 runs and 83.7 minutes total operating time.

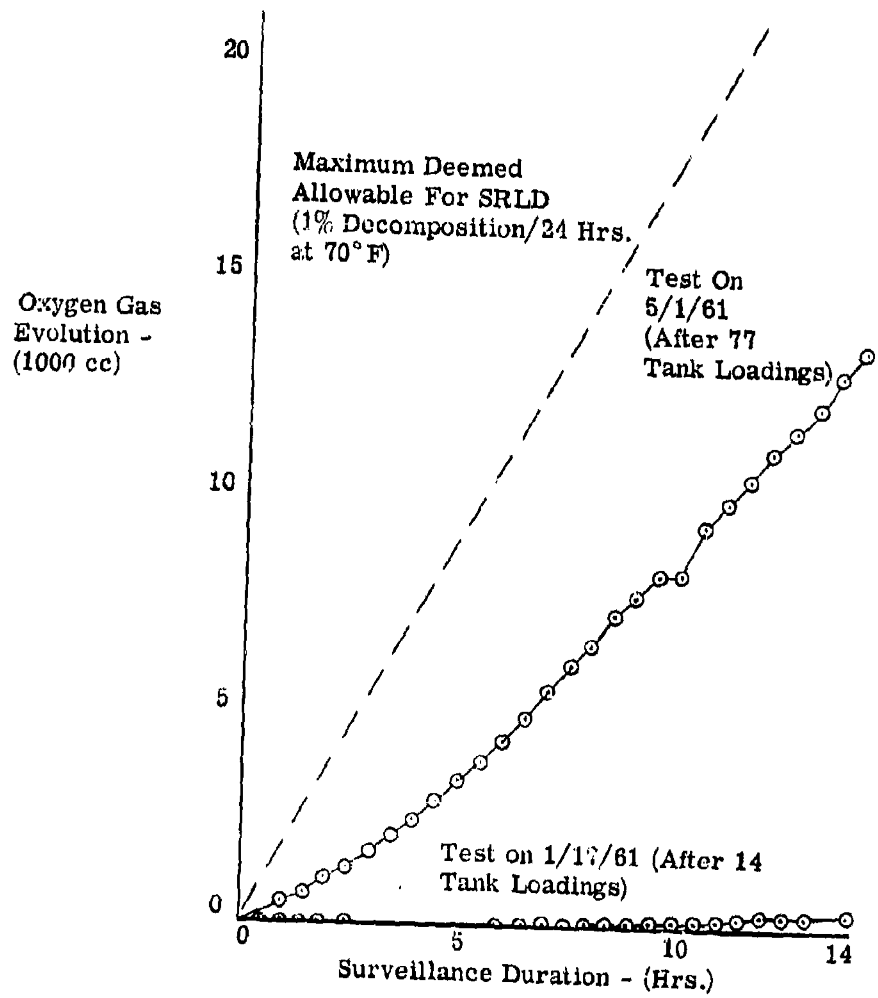


Figure 16. O_2 Gas Evolution Vs. Surveillance Duration Propellant Tanks H_2O_2 Compatibility

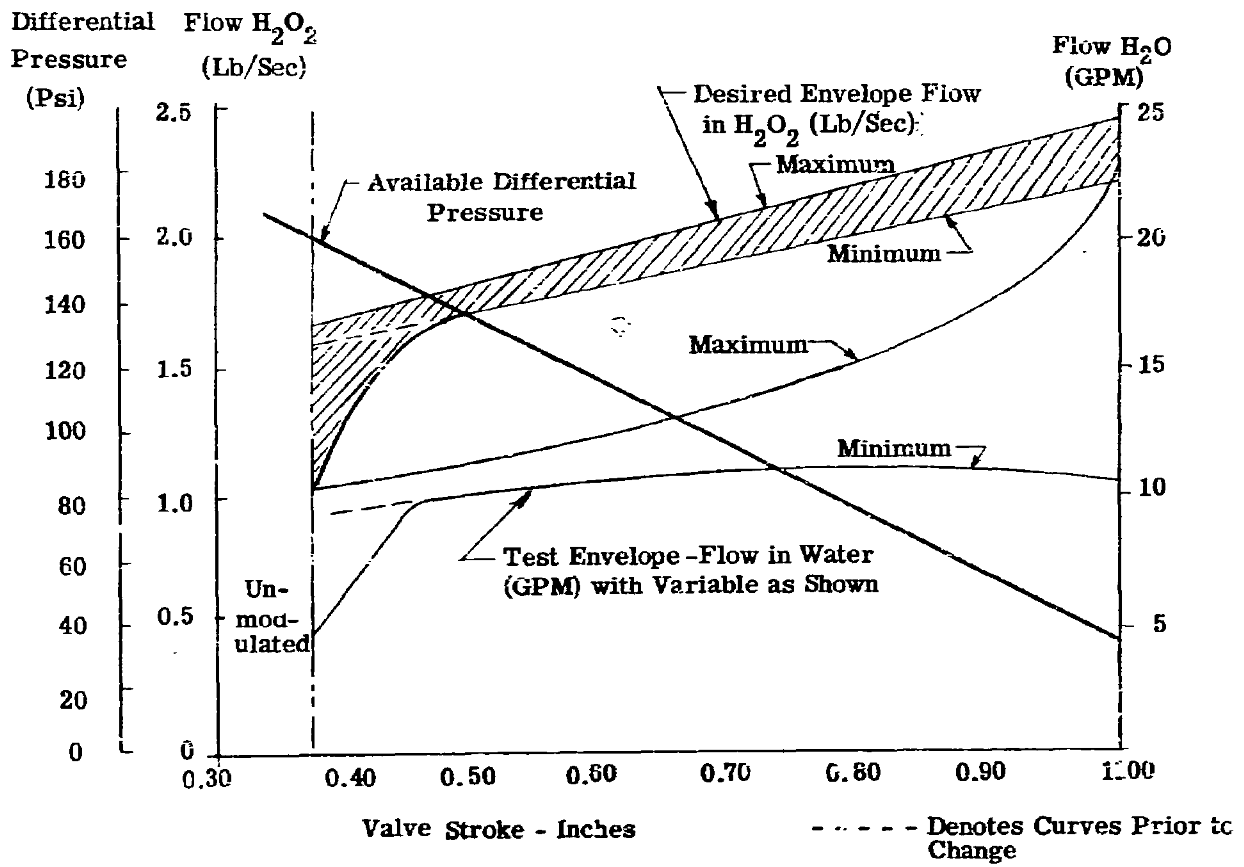


Figure 17. Flow vs Input Stroke Envelope Curves SRED Throttling Valve

III. STABILITY AND CONTROL

A. SUMMARY

The stability and control characteristics of a man supported by a Small Rocket Lift Device (SRLD) have been studied using the analog computer approach. Aspects of the coupled roll-lateral translation motion and vertical take-off and descent were investigated. Design lateral control moments were found to be excessive for satisfactory contol. The need for a lateral stability augmentation device was not established by the analog studies. A twist type throttle was found superior to a squeeze type. Changes were made on the design SRLD hardware based on recommendations stemming from the above studies.

B. INTRODUCTION

Early tethered flights on SRLD test rigs powered by compressed nitrogen showed certain undesirable stability and control characteristics. Fore-aft pitching and translation were satisfactory, but lateral translation and rolling motions were oscillatory and for the most part uncontrollable.

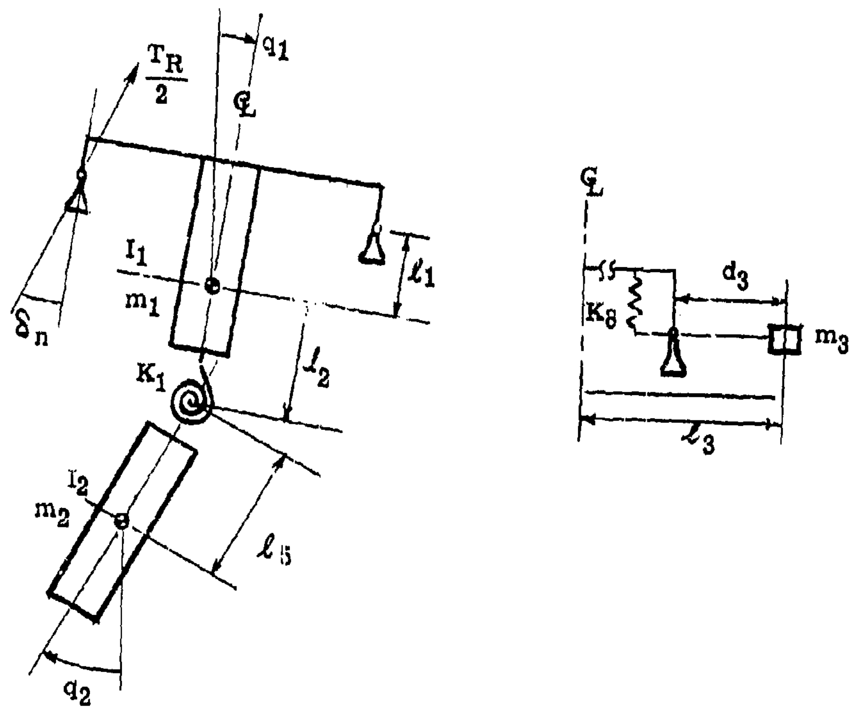
Because of the experience on the tethered nitrogen rig, initial studies were concerned with the effect of a simple stability augmentation scheme on the uncontrolled system dynamics. Subsequent analog investigations used a human pilot as part of the system dynamics for studies of the controlled lateral behavior.

When tethered flights began with the hydrogen peroxide propulsion system, the design throttle gave thrust modulation difficulties. This problem was also instrumented on the analog computer.

The following discussion outlines the analyses and presents the pertinent results which have been documented throughout the program.

C. METHOD OF ANALYSIS

Equations of motion were derived for the model of the man-machine combination and stability augmentation device shown in Figure 18. The equations, also describe lateral behavior and were instrumented on an analog computer. A human operator was required to control his simulated



$$I_1 \ddot{q}_1 - m_1 g \ell_2 q_1 - K_1(q_2 - q_1) + 57.3\, m_1 \ell_2 \ddot{x} = \frac{T_R}{2}(\ell_1 + \ell_2)\, \delta_n$$

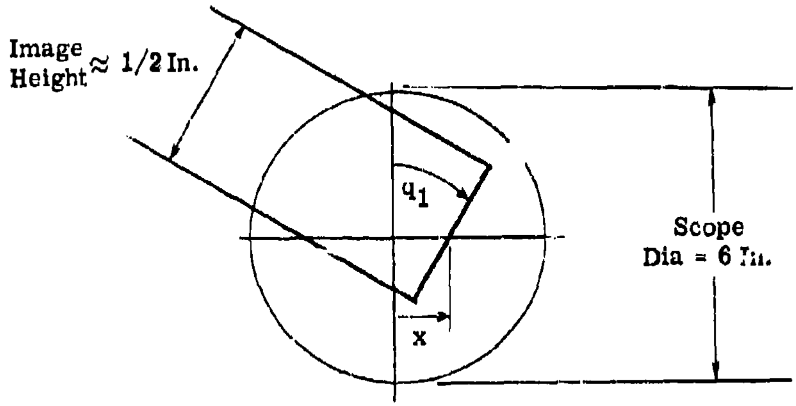
$$I_2 \ddot{q}_2 + m_2 g \ell_3 q_2 + K_1(q_2 - q_1) - 57.3\, m_2 \ell_3 \ddot{x} = 0$$

$$57.3\,(m_1 + m_2)\ddot{x} + m_1 \ell_2 \ddot{q}_1 - m_2 \ell_3 \ddot{q}_2 = T_R q_1 + \frac{T_R}{2}\delta_n$$

$$\ddot{\delta}_s + 2\zeta\, \omega_n \dot{\delta}_s + \omega_n^2 \delta_s = -\frac{\ell_5}{d_3}\ddot{q}_1$$

$$\delta_n = \delta_c + \delta_s$$

Figure 18. Schematics of Man-Machine Combination and Stability Augmentation Device; Equations of Motion



q_1 = Upper Body Attitude, Degrees

$x \propto$ Lateral Displacement, Ft

Scope Display Ratios:

1 Deg Scope = 1 Deg Attitude

2 In. Scope ≅ 20 Ft Lateral Displacement

Figure 19. Oscilloscope Display Schematic

motion based on observations of a moving image displayed on an oscilloscope screen. Figure 19 is a schematic of the display image seen by the pilot, and Figure 20 is a photograph of the test equipment. The control stick shown in Figure 20 is the one incorporated in the original design.

The mathematical model used for take-off and landing studies was simpler than the one used for lateral studies. It consisted of a variable mass body with a single degree of freedom. Figure 21 shows the equations of motion and the thrust-throttle valve-control stick characteristics. The operator's task was to control the vertical motion of a pip on the oscilloscope screen. Figure 22 shows the twist type throttle used in the studies.

D. RESULTS AND DISCUSSION

The studies of the controlled lateral behavior consisted of two parts. The first was a systematic evaluation of the stability augmentation system. The second considered the effect of changing parameters in the equations of motion.

The results of the stability augmentation tests were not enlightening. Twenty-five combinations of frequency and damping were studied but no significant effect on the controlled lateral behavior was noticed. It was concluded that the stability augmentation system might be of secondary importance and, possibly, not necessary. Flight tests have substantiated this conclusion. 28 free flights have been accomplished to date. Each has been successful without the use of a lateral stability augmentation scheme.

Following the stability system tests, other parameters were varied and the effect on the controlled lateral behavior noted. It was soon discovered that changes in both maximum nozzle deflection and nozzle gimbal point height above the system c.g. were pertinent parameters. This, of course, was expected since these parameters determine the maximum rolling moment.

It was surprising to learn, however, that the controlled behavior was more satisfactory when maximum control moments were reduced from the design value. On the basis of these tests, the SRLD hardware was modified to give a maximum rolling moment of 2.4 foot-pounds, which is roughly one-half of the original design value.

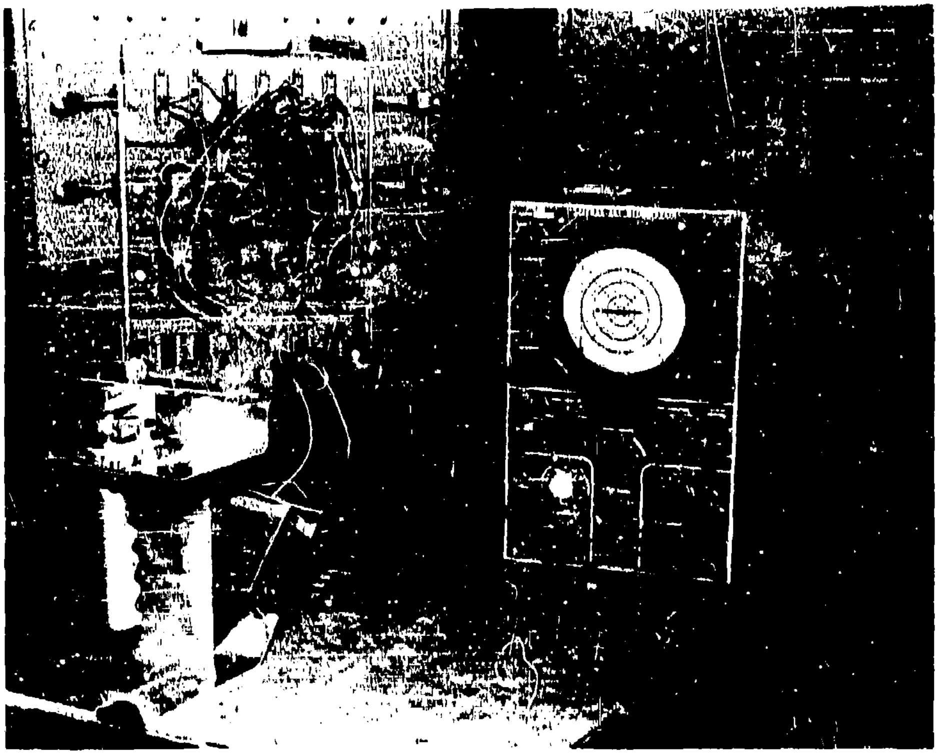


Figure 20. Control Simulation Test Setup

Equations

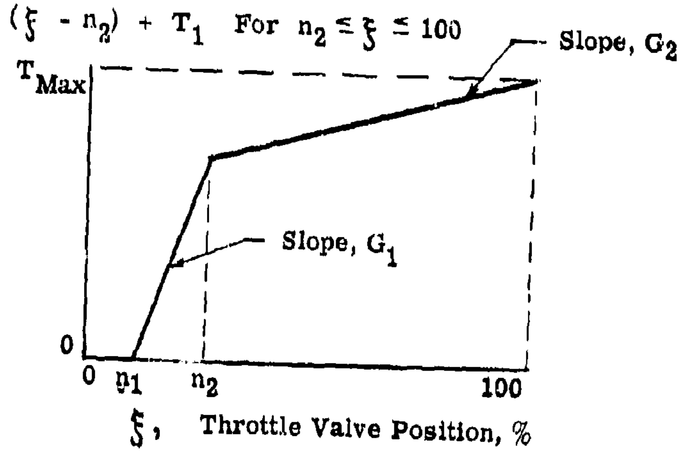
$T = Ky = m\ddot{y}$ Ground Contact Conditions

$T = W_t = m\ddot{y}$ Hovering

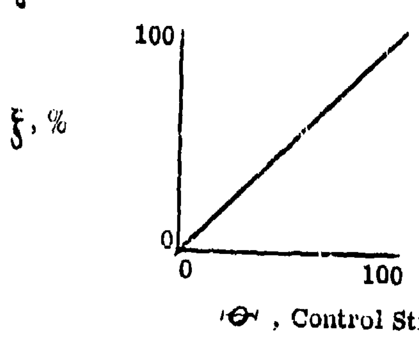
$T = 0$ For $0 \leq \xi \leq n_1$

$T = G_1(\xi - n_1)$ For $n_1 \leq \xi \leq n_2$

$T = G_2(\xi - n_2) + T_1$ For $n_2 \leq \xi \leq 100$



$\xi = \theta$



A. Linear Relation is Assumed Between Throttle Valve Position and Control Stick Position

Figure 21. SRLD Take-off and Hover Dynamics

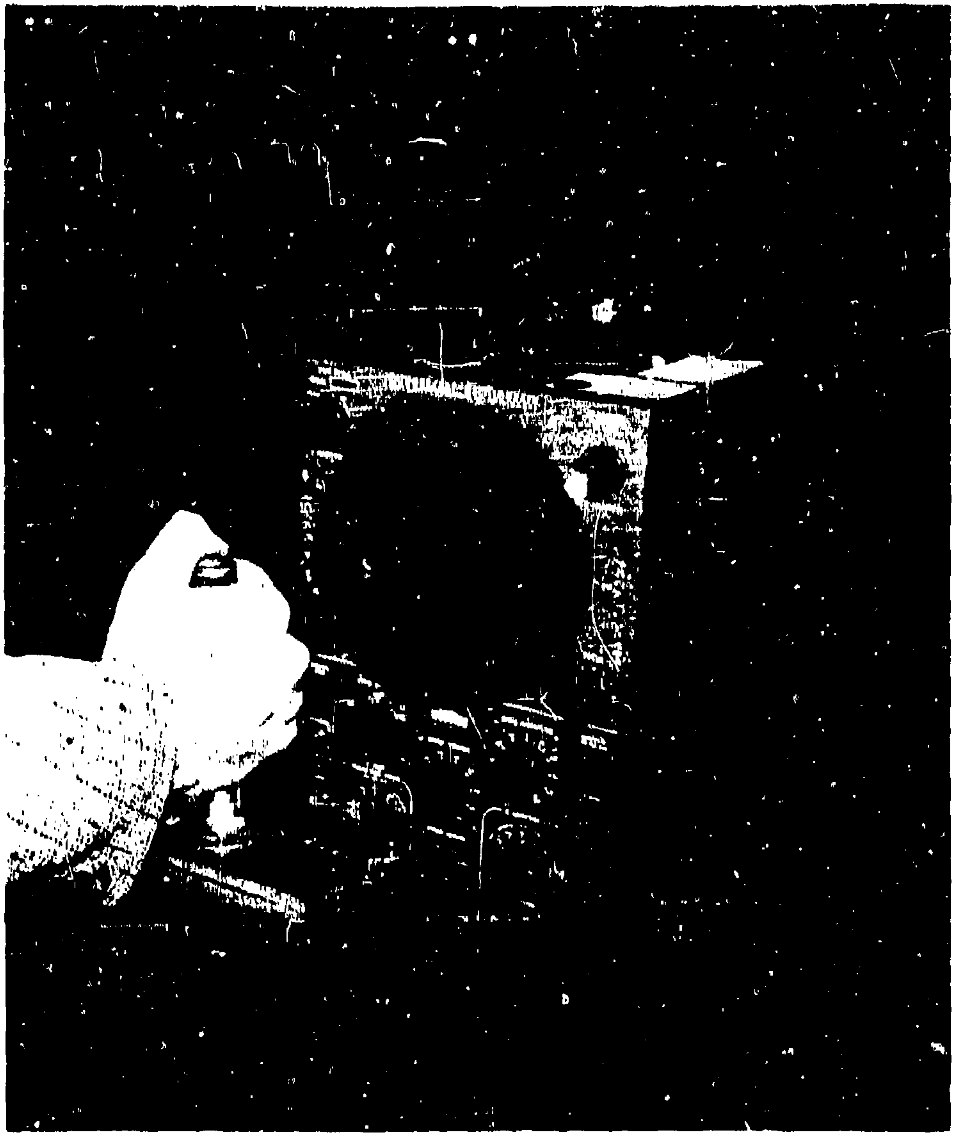


Figure 22. Analog Computer Test Setup with Rotary Type Throttle

The choice of maximum nozzle deflection and nozzle gimbal height above the c.g. is not dictated by moment requirements alone. Nozzle deflection also introduces a side force which produces linear accelerations. Small nozzle deflections at larger moment arms can give moments equal to those from large nozzle deflections at small moment arms. In the latter case the forces available for linear acceleration and deceleration can become very large.

One of the advantages of using an analog computer was exemplified during these tests. Pilots observing the oscilloscope display rated the over-all behavior of the coupled roll-lateral translation motions. Two of the three pilots involved had acquired previous tethered flight experience. Although their response characteristics differ between real and analog flights,they could express judgement concerning the desirable and undesirable behavior observed on the oscilloscope screen.

Another parameter which affected the controlled lateral behavior was the hip spring constant. Low values are undesirable; high values are most desirable. Since this parameter is most probably highly dependent on both physiological and psychological factors, its exact value and nature at any instant are unknown. Physically, the operator could be stiffened at the hips. During the early tethered flights a simple method of achieving this was not conceived and complete immobilization was considered impractical and possibly unsafe. It was noted, however, that tethered flight performance showed considerable improvement when a"belly-plate"was used. This belly-plate was a lower abdominable support and was added for physiological reasons. It is believed that this support resulted in an increased hip spring constant at least to the extent where the effects on flight dynamics were apparent. To date, free flights have not been performed without it.

Studies of vertical take-offs and landings were initiated after early tethered flights indicated thrust modulation difficulties. Two throttle types were evaluated in conjunction with various thrust control gradients, i.e., thrust versus throttle position relations. One throttle was a"squeeze" type and the other was a "twist" type. Results from the computer studies definitely established a trend favoring the twist throttle. The design thrust gradient was considered satisfactory. This was gratifying since the thrust gradient is a function of the throttle valve flow characteristics. The need for valve redesign was thus unnecessary.

Another recommendation stemming from the vertical flight studies was the installation of a detent on the throttle grip. The purpose of the detent was to provide a cue to the pilot when the thrust level reached 70%. It was felt that this cue would prevent excessive thrust reduction during a letdown and thereby result in smooth landings. During early free flights the operator did not comment on the detent. After a number of flights, however, his comments mentioned the detent specifically.

He felt that the presence of the detent and the simple cue it provided improved his landing or let-down performance.

Figures 23 and 24 are views of the original design and modified throttle and control sticks.

The flight operator's comments on factors affecting flight control of the SRLD are discussed in the following paragraphs.

The flying of the belt requires consciously and slowly applied control movements. This effort is particularly important during the initial lift-off (time from throttle actuation till feet leave the ground) phase of the flight when no control reference is available. The operator should attempt to lift-off to a hovering altitude of one foot or higher. Once "airborne", the basic controls (throttle, pitch, and lateral) become instinctive (with experience) and easy to direct. Yaw control, as presently manipulated, is not truly instinctive, but requires slightly more "thinking time" to bring about the desired yaw reaction.

It has been the operator's experience that the best SRLD control occurs at altitudes in excess of three feet, presumably because the degree of control error becomes more critical nearer the ground.

Of the many fears and apprehensions the operator initially experienced when he first was associated with the SRLD, there are only two, of major consequence, remaining:

(1) The possibility of inadvertently reducing thrust below the 70% "drop off" level and its associated rapid descent. This has been reduced as a result of increasing the resistance of the (70% thrust) detent. The resistance is such that now, 14 inch-pounds of torque has to be applied to cut the throttle past this 70% level. During the descent phase of free flight 27, this detent was felt and signaled the operator to lessen his throttle decrease. Had it not

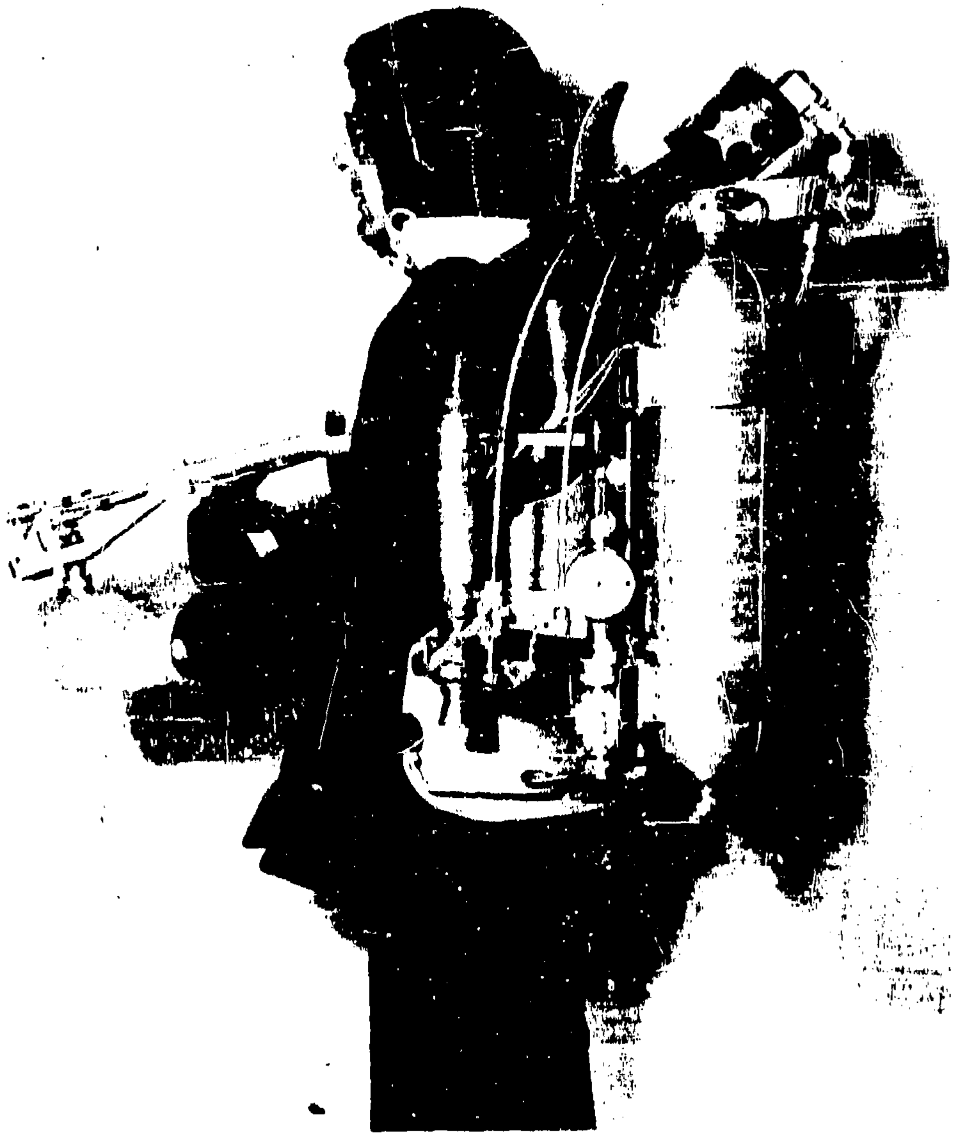


Figure 23. Original Throttle and Control Stick

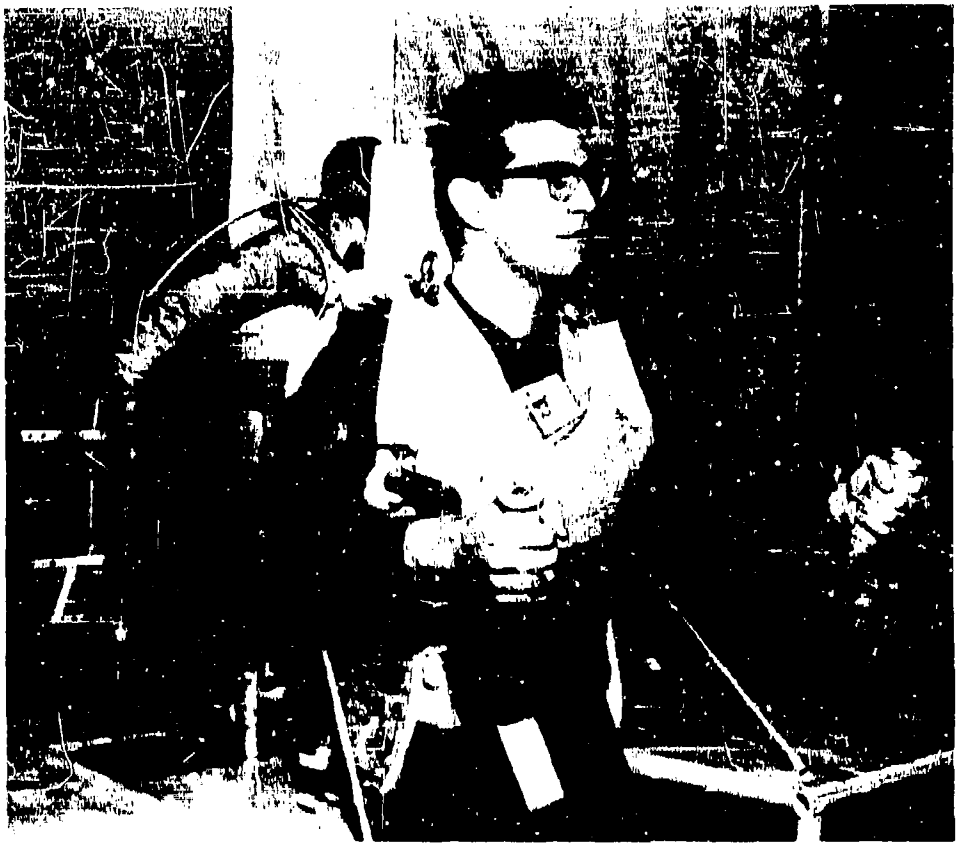


Figure 24. Modified Throttle and Control Stick

been for this detent "signal", the operator may very well have "cut his thrust" at an altitude of four feet.

(2) The possibility of propellant depletion or "burn out" while still in flight. This was greatly reduced with the advent of the "vibrator type" propellant depletion warning device. This device gives the operator a definite indication of how he stands propellant-wise without further taxing his visual senses.

The in-flight controllability fears are nil inasmuch as no aberrations have been encountered that could completely put the operator "out of control." Our only control problems have been in yaw, from which the operator can easily "save himself" by a slow descent. We have had three "uncontrollable" yaw problems in free flight, all followed by slow descents to safety.

The throttle (altitude) control is about as good as could be desired. It is instinctive, easy to operate, easy to learn, and provides the very small thrust variations that are required for a smooth and level flight. The ability of this control system to regulate the thrust to maintain constant altitude of flight (i.e. ±1 foot) with the system losing weight at the rate of 2 pounds per second is remarkable.

The "dead man" throttle return spring is a "must" as was determined during the four tethered flights (No. 30, 31, 32, and 33), when control direction was momentarily lost. The spring "feel" enables the operator to instinctively apply the desired type of throttle control change (i.e. increase or decrease).

The "low level" (70% thrust) detent is a very important safety feature that should be maintained and improved upon. The thrust drop off below this 70% level is very sharp and as such is uncontrollable. There should have to be a concerted and definite operator effort to pass this 70% level to insure that this level would not be passed while the SRLD is in flight.

Pitch control actuation is very nearly instinctive. On occasion, however, a conscious effort must be "thought out" to increase translation speed, (i.e., you find yourself moving too slowly, almost hovering). You stop and say to yourself "speed up - - - lower the control arms."

During hover and slow-down, prior to landing, the pitch manipulation is instinctive with no "brainwork" required.

Initial "take-off" pitch control alignment is especially important (i.e. ±3 degrees) to insure that no translation motions are instigated until the operator is completely airborne. This alignment is not difficult, as the operator simply takes a visual check to see that the "gas ducts" are directed straight downward.

With the range of pitch control we now have, much greater translation acceleration forces are available than the operator has used. The maximum translation velocity reached to date is approximately 35 mph. This was performed at low altitude (i.e., $<$ 4 feet). Faster velocities would have to be performed at greater altitudes (8 to 10 feet) where altitude deviation is not as critical.

The ability to move laterally in small amounts (i.e. correcting for cross winds or making radius turns) has been readily demonstrated. This control is actuated by tilting the arms in the lateral direction desired. Movement of the arms is easily done and is instinctive in nature. No "mental work" is required.

The correlation of lateral and yaw control, as in radius turns, takes practice to perform smoothly (rather than jerkily, in step fashion). This roughness is due primarily to yaw difficulties rather than lateral control.

As with pitch control, lateral control must be applied slowly and smoothly to limit the degree of "upsetting" acceleration forces. As experienced on the first attempt to fly a slalom course, "playing rough" with the controls will quickly put you in an impossible control situation.

Of all the control operations, yaw requires the most "thinking concentrating time". The method of yaw control (i.e., applying torque to a vertical handle) does not lend itself readily to natural or instinctive reaction, and a longer training period is thereby involved. The similarity of this type of the control with the throttle control of the right hand caused a cross-hand control problem (Free Flights 12 and 21), which results in induced yaw (left hand) when actually more thrust (right hand) was called for.

The magnitude of the turning torque (i.e., reaction forces applied at jetavators) resulting from maximum yaw actuation is deemed adequate (i.e., the torque is sufficiently strong to turn the operator "with haste"; yet not so great as to "whip the operator" or noticeably affect the vertical component of thrust).

A tilting or steering type of yaw control should make yaw control easier to operate and eliminate the inter-arm crossover control problem.

IV. HUMAN FACTORS

Human Factors support was provided throughout the Phase II Program to assist in formulation and, as necessary, revision of SRLD flight-test plans in integrating detailed procedure requirements for checklist control of the test operations, maintaining current revisions to the checklists, and acting in an advisory capacity on safety and flight-test practices. During this phase, recommendations were also prepared for SRLD analog simulation problems and procedures as well as on pertinent modifications of the SRLD lifting configuration. Throughout the test program, operator performance criteria were established, evaluated, and revised to determine, as much as possible, evident patterns of skills and proficiency development. Preliminary estimates of personnel selection and training requirements were also completed in the Phase II study.

A. FLIGHT-TEST PLANS.

Early flight-test plans, prepared on a prior basis, considered a simple-to-complex sequence, for operator performance, to begin with a hovering task, then to try lateral translation, turning, forward translation, followed by a task to combine all these functions. However, after the first few exploratory flights under tether, it was evident that the original plans required revision. Figure 25 illustrates a revised sequence of flight plans based partly on likely field operational requirements for translation, hovering, let-down and turnaround. This sequence was suggested since it began with those flight-tasks that seemed to be most easily accomplished by the flight operator as evidenced by his early performance.

Early flight-test objectives were primarily concerned with establishing an acceptable control configuration on the basis of flight-operator and observer opinion criteria. Exploratory flights were continued (a total of 42 flights with the two different operators) until a configuration was established as acceptable. The remaining flight plans were then developed, in some combination of those plans illustrated in Figure 25, to provide for proficiency in performance of the flight operator. In this final configuration, a total of 14 remaining flights were conducted under tether. The remaining have been free flights conducted out-of-doors in open terrain.

B. FLIGHT-TEST CHECKLIST.

Required flight-test procedures were integrated throughout Phase II, considering such things as safety and efficiency in the conduct of the program.

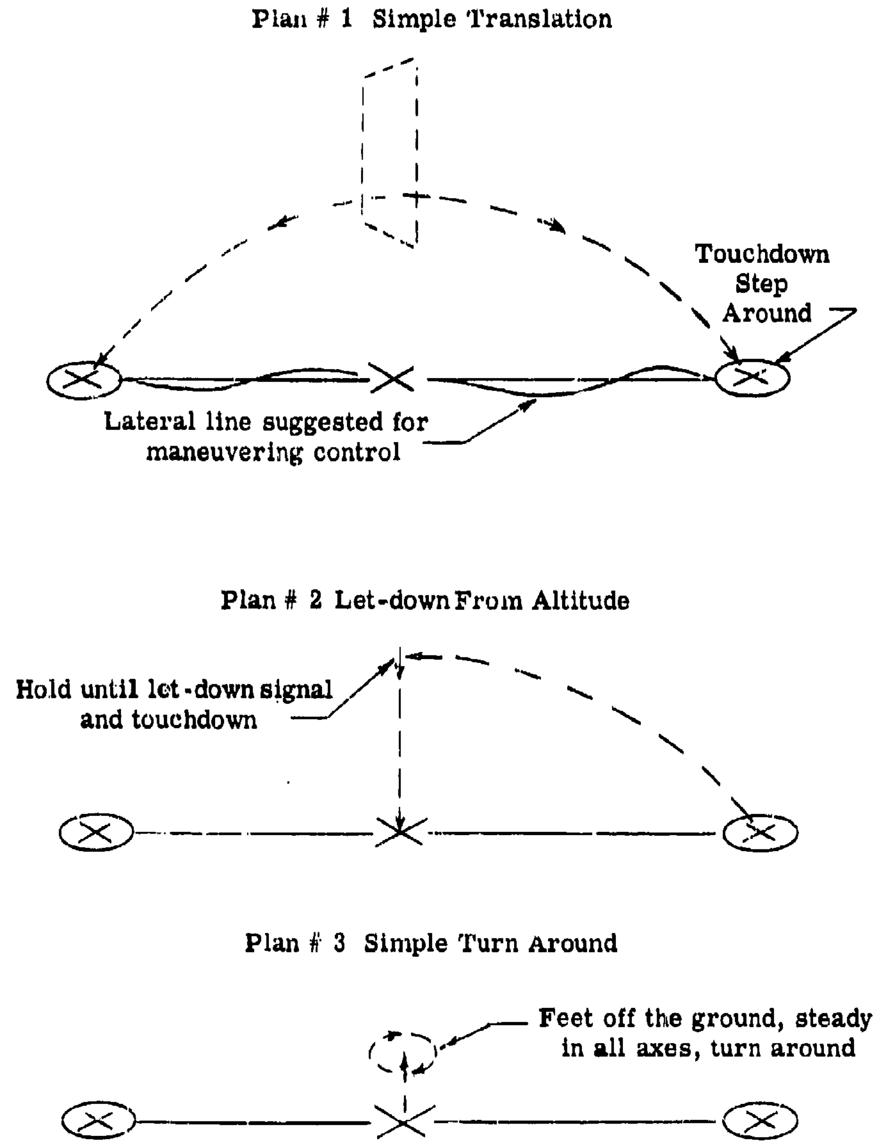


Figure 25. Flight Program for SRLD Tests Leading to Free Flight

Procedures were developed into checklist form, which was maintained and/or revised as necessary throughout the program. Sites and procedures employed in both tethered and free-flight tests are presented in Appendix I.

Four different sites were employed in tethered-flight testing. The first site, Building 67, was chosen since it was convenient for peroxide handling and appeared to have ample space. Decision was made to move outside when the room inside the building proved to be too restrictive. Site No. 2, with the tethering cable between two towers across a roadway, presented an impingement problem at the shoulder. Several flights were then completed at Site No. 3 on a solid concrete ramp, until extremely low outside temperature resulted in the exhaust steam's obscuring the operator's vision as well as that of the tethering men and observers. The fourth site, inside the experimental hanger, was selected since temperature was controlled and ample space was available. Remaining flights under tether were completed at this site.

Free-flight testing was begun on April 20, 1961. The first flight was performed over the grass on Niagara Falls airport near the threshold of Runway 32. (Free-Flight Site No. 1.) This first free-flight site was selected because of the soft turf available, for safety reasons. A decision was made to employ the second site off the ramp due to proximity of the first site to a public road. Subsequent sites at the Niagara Frontier Golf Course were selected to provide for demonstrations of various flight problems over soft turf.

C. ANALOG PROGRAM RECOMMENDATIONS.

During the course of the Phase II program, further consideration was given as to how the REAC analog computer might be used to provide control-design data, as well as to provide effective auxiliary training for the flight operator. The primary control considered was that of the throttle, since this basically seemed to be most problematic. An experimental plan was prepared, and is presented in Appendix II. The intent of this recommended procedure was to establish simulated conditions in order to provide for the greatest amount of positive training transfer effects to the operational task, and to control experimental variables such that valid conclusions about desirable throttle configuration might be made. The study as outlined, however, was not implemented due to limited scope of the program.

D. LIFTING CONFIGURATION RECOMMENDATIONS.

Further recommendations, in the Phase II program, were prepared for design of SRLD lifting structure. The design being flight tested was that of a limited area of lift about the axillae or arm pits. This was discussed by human-factors and medical personnel as undesirable, since circulation to arms and hands tended to be restricted. Further disadvantages were considered to be in control interference, and discomfort to the operator. For these reasons, a preliminary study, as outlined in Appendix III, was recommended to establish an optimal lifting configuration. Two configurations to be studied included a band about the arm rings distributing the lifting stress over a wider area about the large latissimus dorsi muscles, and a band at the ridge of the iliac crest.

The study as outlined was not implemented because of limitations in the flight-test schedule. However, beginning with flight number 23, of the second flight operator, the lifting configuration was modified to incorporate these two principles, i.e., increasing the lift area at the axillae, and banding about the iliac crest. All subsequent flights have been performed with the modified configuration.

E. MEDICAL DATA ON FLIGHT-TEST OPERATORS.

Two different flight operators were employed in SRLD test flights: Operators Wendell Moore and Harold Graham.

Complete physical examinations were made of each operator to assure physical fitness for the flight tests. The examinations included chest X-rays, electrocardiograms, blood counts, urinalyses, complete skeletal X-rays and surveys, audiometric evaluation, visual acuity and vital-capacity measurements, and complete neurological examination. A clinical judgment was also made of the operators' mental attitudes about flying the rig, including psychological evaluation on the basis of their past experiences, domestic situations, financial position, and motivation to embark on the project.

Pertinent anthropometric measurements were also completed for each operator, as presented in Table 1.

Medical personnel were in attendance for each flight test.

Immediately prior to and following each flight test, the operator's blood pressure, vital capacity, pulse, and respiration were examined. Clinical judgments were also made concerning effects of the flight on the operator's attitude, his subjective feelings prior to and postflight, his preflight apprehension and over-all description of sensations in flight.

TABLE 1

ANTHROPOMETRIC DATA RECORD

	Wendell Moore (8-22-60)		Harold Graham (6-28-61)	
	Measurement	Centile*	Measurement	Centile*
Age	42		27	
Weight	147.5 lb	24	160 lb	50
Stature	69.5 in.	57	70.5 in.	73
Cervical Height	59.5	57	64.0	98
Shoulders Height	58.2	77	59.0	87
Suprasternal Height	56.5	53	57.2	66
Waist Height	43.5	80	44.5	91
Crotch Height	32.5	43	33.0	55
Sitting Height	35.0	25	37.0	80
Buttock - Leg Length	41.8	33	43.5	65
Arm Span	69.5	33	71.0	53
Arm Reach, Maximum from Wall	33.5	25	37.5	29
Elbow-to-Elbow Breadth	17.0	45	20.0	96
Hip Breadth	13.3	55	13.0	40
Shoulder Breadth	18.0	55	18.5	75
Chest Breadth	11.5	25	11.6	30
Waist Breadth	10.5	45	11.1	70
Chest Depth	9.7	80	8.5	22
Waist Depth	9.7	96	7.2	20
Neck Circumference	14.8	40	15.2	65
Shoulder Circumference	43.5	23	42.7	14
Chest Circumference	36.3	15	36.5	17
Waist Circumference	32.5	60	33.2	68
Vertical Tank Circumference	62.0	16	63.0	27

*Anthropometry of Flying Personnel - 1950 WADC TR 52-321

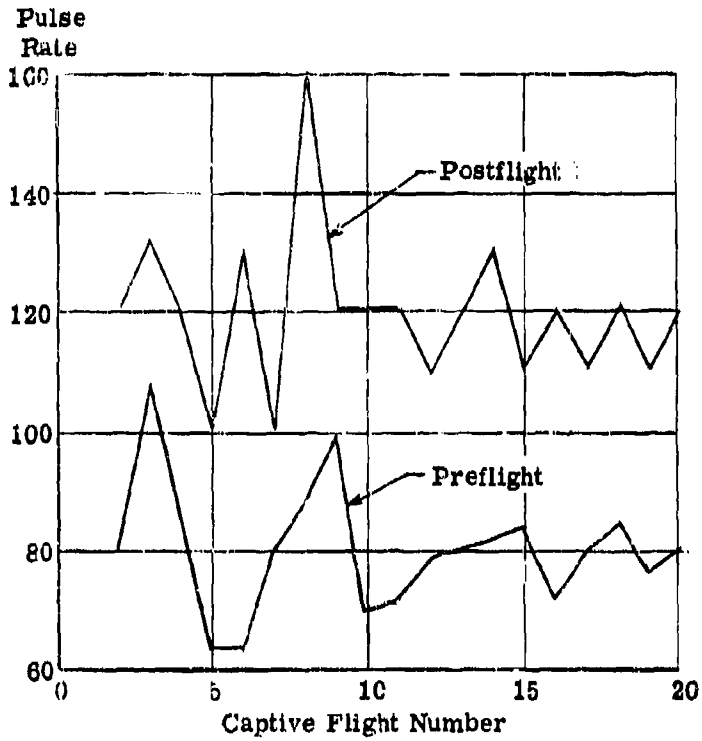
From Figures 26 and 27 can be seen the operators' adaptation in successive flight tests. Note that the adrenogenic reaction, or the general level of excitement, tends to fall off with successive flights. No attempt was made to correlate these data with performance parameters during the Phase II program. However, general inspection of the preflight plots further indicates significance with respect to incidents of a previous flight and conditions inducing apprehension surrounding each flight. In Figure 26, for example, the preflight pulse rate of the first operator was high prior to flight number three. This is suggestive of apprehension in going to outside Tethered Site No. 2. Also, he had incurred injury during the previous flight, which may have further induced apprehension. Note from Figure 27 that the second flight operator's apprehension seemed also to increase, as indicated by preflight pulse rate, for flight No. 29 and 30. This may have been due to stated intentions to perform free flights, and the attendant anticipatory excitement. The postflight pulse measurement plot, may, in general, be more indicative of adaptation and learning, i.e., elimination of random and excessive muscular tensions with increasing familiarity and skill.

During the course of the development program, Dr. Kelly of the Bell Medical Department provided advice on the physiological effects of flight, and proffered suggestions on the temporal spacing of successive flights to improve learning effects, provisions for necessary protective devices, and torso packaging techniques in order to distribute lift effects.

Protective devices were incorporated for the operator such as elbow, shin, and knee guards, and a metallic groin protector.

A warning device was also developed to alert the operator to the fact that fuel was running low. A visual signal, in the form of a red light attached to his helmet, was abandoned since the operator in flight frequently missed seeing the light. Likewise, an air conducted auditory signal employed failed to attract the operator's attention. A vibratory signal was then incorporated in the helmet to stimulate the operator at the back of the skull by bone conduction. As a timer function, after 15 seconds, it was activated every second and became continuous after 20 seconds. This proved effective in alerting the operator to a low-fuel situation.

Improved packaging of the operator in lift was also accomplished. Relative immobilization of his vertebral column was accomplished by means of distributing lift about pectoral and iliac crest areas, plus additional straps and abdominal plates which were incorporated to limit not only the pooling of blood in the abdominal cavity but also to diminish any element of anoxia elsewhere. Increased padding was provided on the arm rings to distribute the



Note: Graph Shows Operator's Highest and Lowest Pulse Rate. These were Taken Immediately Before and After Each Flight.

Figure 26. First Operator's Pulse-Rate Data Throughout Early Captive Flights

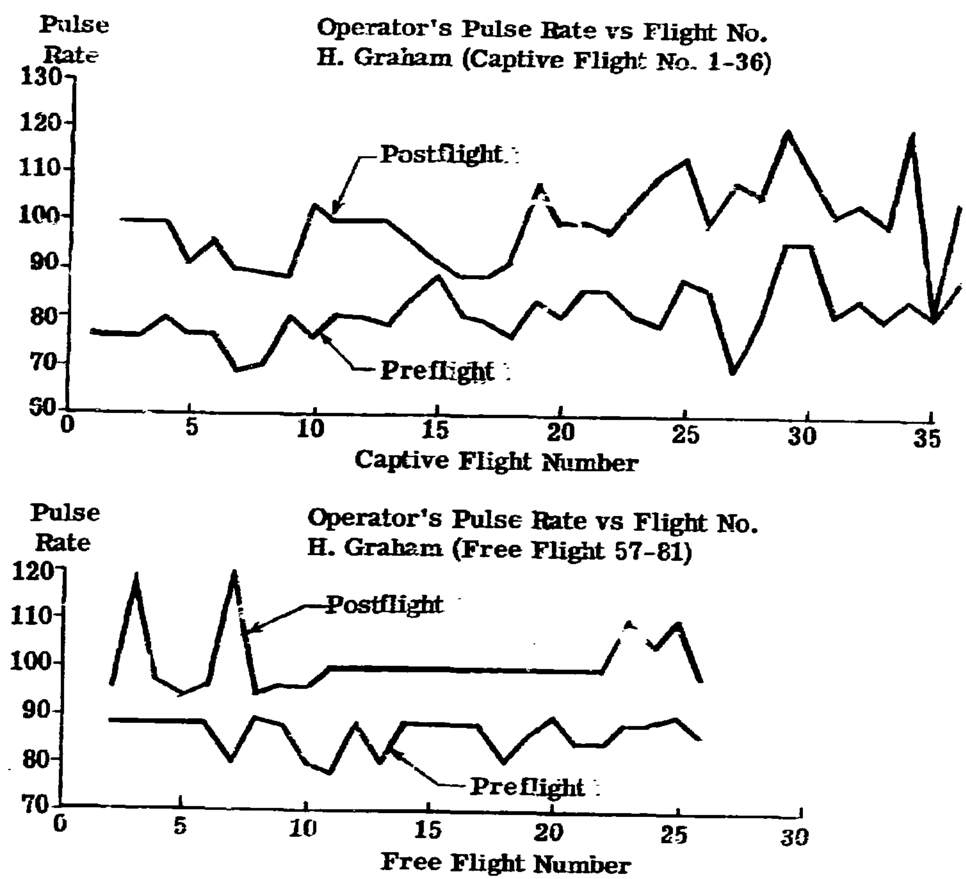


Figure 27. Second Operator's Pulse Rate Data Throughout Captive and Free Flights

axillary pressures, partially to the pectoral areas, to diminish the tendency to axillary compression of blood vessels and nerves - and at the same time to render the degree of mobility of the spine to a bare minimum - thus in effect putting him en cuirasse.

F. FLIGHT-TEST PERFORMANCE EVALUATION.

Evaluation criteria were generated on the flight-operators performance, in SRLD test flights, in the form of operator and observer ratings. A ten-point rating scale was developed for early flights as illustrated in Table 2. This scale was used for the first 6 flights. Results are summarized in Table 3.

The ten-point scale proved to be unsatisfactory since parameters were not consistently rated by all observers and the scale did not seem to elicit careful discriminating judgments. For this reason, a five-point scale was developed as illustrated in Table 4. This scale was used by observers for the remainder of 20 flights, results of which are summarized in Table 5.

Neither the ten-point nor the five-point scale seemed adequate for performance evaluation. Note that in Tables 2 and 4 no evidence in improvement of operator performance was apparent. On subsequent flights, employing a different flight operator, the scales were not used. Rather, general descriptions of each flight were prepared for subsequent qualitative evaluation of the operator's proficiency.

In the Phase II Program, a total of 84 flights were completed, 56 being under tether control and 28 in free flight. The first 20 tethered flights were completed by Operator Moore. 64 flights were completed by Operator Graham, the last 28 of which were free.

As discussed previously, medical data were obtained prior to and following each flight, including such parameters as blood pressure, vital capacity, and pulse rate. Figures 26 and 27 present pulse-rate data on all flights, for the first and second flight operators respectively.

All tethered flights but the first 6 were conducted in the experimental hanger, where temperature varied between 50 and 60 degrees F. No exhaust steam or impingement problems were noted. However, at the outdoor tethering sites, temperature varied from 8 to 43 degrees F. Visibility through the exhaust steam appeared to become severely problematic at the lower temperature extremes.

Temperature and relative humidity are significant to the formation of exhaust vapor and to obscuring visibility. Temperature appears to be most

TABLE [illegible]

Test Date ________ SMALL ROCKET LIFT DEVICE FLIGHT RATING CHART Test No. ________

(Please check one number for each Rating)

	1	2	3	4	5	6	7	8	9	10
General Rating	Excellent Completely Confident	Good Easy to Control	Satisfactory Minor Difficulties in Control	Acceptable Difficult to Control	Marginal Not much Confidence	Unacceptable Control Extremely Difficult	Impossible Cannot be Controlled	Hazardous Injury Could Result	Dangerous Operator Was Hurt	Killer Fatal Injury May Result
Roll-or-Lateral Control Rating	Steady and Controlled		Oscillations Quickly Corrected and Trimmed		Oscillations Difficult to Control, Cannot Trim			Severe Oscillations Cannot be Controlled		Oscillations and Direction Cannot be Controlled
Pitch or Fore-and-Aft Rating	Steady and Controlled		Moments Quickly Corrected and Trimmed		Moments Difficult to Control, Cannot Trim			Severe Moments and Oscillations Cannot be Controlled		Oscillation and Direction Cannot be Controlled
Yaw Rating	Steady and Controlled		Spin Oscillations Quickly Corrected		Spin Difficult to Control			Spin Rate and Oscillations Cannot be Controlled		Spin Oscillations and Direction Cannot be controlled
Control Cross-Coupling Rating	Uni-Directional and Steady		Some, But Easy to Control		Interference Difficult to Control			Interference Cannot be Controlled		Sets Up Uncontrollable Omni-Directional Interference
Translation Control Rating	Accurate and Precise		Close and Adequate		Poor Control			Way Off Target		No Control Whatsoever
Body Control Rating	Easy Posture and Deliberate Movements		Body Somewhat Tense, But Control Easy		Disturbing Moments Induced. Posture Difficult to Control			Limbs Flail, Tense, No Control		No Control Whatsoever
Vertical Control Rating	Accurate and Precise Smooth Takeoff and Landing		Some Fluctuation Easily Controlled		Difficult to Maintain, Takeoff and Landing Irregular			Cannot Be Controlled, Hard Takeoff and Landing		Control Impossible Takeoff and Landing Dangerous

TABLE 3

SUMMARY OF OBSERVER RATINGS ON 10-POINT SCALE FOR FIRST SIX CAPTIVE FLIGHTS (EXPLORATORY)

Parameter	Range of Rating						Ave. of Rating						No. Rating This Parameter					
Flt. No.	1	2	3	4*	5	6	1	2	3	4*	5	6	1	2	3	4*	5	6
General	4-7	4-9	1-3	3-6	2-3	2-5	5	5	3	5	3	3	4	5	8	5	5	5
Roll	-	2-4	2	-	2	2	-	3	2	-	2	2	0	2	2	-	1	1
Pitch	6	5-10	1-4	3-6	1-3	3	6	7	3	5	2	3	1	3	7	2	3	2
Yaw	5	2-6	-	-	1	-	5	4	-	-	1	-	2	3	-	-	1	-
Cross Coupling	6	9	-	4	-	-	6	9	-	4	-	-	1	1	-	1	-	-
Translation	4-10	4-9	1-4	4	2-3	2-3	7	6	3	4	3	3	2	2	3	1	3	3
Body Control	2-6	2-8	1-3	2-7	1-5	2-5	4	4	2	5	3	3	6	4	7	3	7	4
Vertical Control	2-6	4-8	1-5	4-6	2-5	2-4	4	6	3	5	4	3	7	4	8	3	4	4

*Aborted after 10 seconds

NOTE: 1 - Good, 10 - Bad

TABLE 4

SRLD OPERATOR PERFORMANCE EVALUATION

1. What was the Flight Operator attempting to do? Please sketch his flight plan as you understood it.

2. What was his actual performance? Please sketch it below.

Please encircle one number for each scale!

	Accuracy	Flight Characteristics	
1	As programmed-Landed on mark	Excellent	1
2	As programmed-Close to mark	Good	2
3	As programmed-Way off mark	Fair	3
4	Erratic-Close to mark	Poor	4
5	Erratic-Way off mark	No control	5

Comments: (Continue on back)

TABLE 5

SUMMARY OF RATINGS ON 5-POINT SCALE FOR ACCURACY AND FLIGHT CHARACTERISTICS

		Range of Rating									Average								
Flight No.		7	8	9	10	11	12	13	14	15	7	8	9	10	11	12	13	14	15
*N=15	7	1-3									2								
N=19	8		1-4									2.8							
N=13	9			1-4									2.3						
N=13	10				1-4									2.3					
N=13	11					1-5									2.3				
N=11	12						2-5									3.4			
N=15	13							3-4									3.5		
N=18	14								2-5									4.0	
N=20	15									1-4									2.4
Flight No.		16	17	18	19	20	21	22	23	24	16	17	18	19	20	21	22	23	24
N=10	16	2-4									2.4								
N=13	17		2-4									2.6							
N= 9	18			2-4									2.9						
N=16	19				2-5									3.1					
N=12	20					2-5									3.3				

*Total No. of Judgments

critical; for example, on Free Flight No. 6, temperature was 42 degrees F and relative humidity was 79 percent - heavy exhaust vapor developed. During Free Flight No. 10, the temperature was 55 degrees F, and relative humidity was up to 95 percent. No exhaust vapor was noted.

Impingement in flight over soft turf was not severe, and did not appear to harass observers who stood approximately 20 to 50 feet from the blast. However, the flight operator was bothered, and requested goggles, which were employed on Free Flight No. 4 and subsequent flights. Goggles were subsequently "steam-proofed" for Free Flight No. 6, and no further difficulties were noted.

Noise at the SRLD-nozzle source is approximately 135 decibels, peaking between the seventh and eighth octave bands (approximately 4000 cps). On Free-Flight No. 20 a General Radio Sound Level Meter, Type 1551-B, was placed approximately 50 feet from the flight path and noise level was measured to be approximately 125 decibels. Duration at this level was normally less than 20 seconds. No complaints for disturbances at this noise level were noted. The flight operator's helmet provided ample attenuation to the noise near the source Flight crew and observers, who were positioned from 20 to 50 feet from the source, during later flights wore no ear protectors, and seemed to suffer no ill effects.

A specially fitted flight suit was used for the first eight flights. Due to body-mobility restrictions and lack of ventilation, this suit was abandoned in favor of a normal propellant-handler's polyvinyl suit, which was used for all subsequent flights.

Following are described all test flights completed during the Phase II Program. The first operator completed 20 flights under tether. After the first operator sustained injury, due to becoming entangled with the tether rope, the second flight operator completed a total of 36 tethered flights and 28 free flights:

Flight No. 1 December 29, 1960. Tethered Site No. 1 (Refer to Appendix I).

Configuration: Pivot bearing free; stick free in all axes, squeeze-type throttle.

Objective: Familiarization with controls under tie-down conditions.

Performance: The flight operator expressed a high level of confidence, giving a general rating of "3" on the rating chart. As did observers, he, too, considered vertical or throttle control to be most problematic.

Flight No. 2 January 6, 1961 Tethered Site No. 2

Configuration: Same as previous flight (the tie-down tether was fixed for maximum three-foot altitude).

Objective: To test for vertical control.

Performance: Vertical control, in a concensus of observer judgments, still seemed problematic, and, likewise, in debriefing comments, this parameter was considered to give the most trouble in control. Such comments were noted as follows;". . . operator will need more run time to get used to throttle. Throttle control is erratic. He overcontrols - excessive use of fuel prior to take off. The fine control is not acceptable. . . . . doesn't seem able to modulate thrust accurately at moment of lift off. . . . . yawing motion seemed to be coupled with throttle."

The flight operator still evidenced confidence, but considered yaw and vertical control to be marginal. He felt most apprehensive about operating inside the building, having bumped into a wash basin at the wall during this exploratory flight.

Further observations on this flight suggested the following:

1. Inadvertent yaw motion may have been induced in throttle actuation analogous to that induced by the trigger squeeze in rifle firing.
2. Further insulation about the exhaust pipes is required to protect the operator.
3. Stricter procedures must be instituted to improve flight safety.

Flight No. 3 January 11, 1961 Tethered Site No. 2

Outside Temperature: 43 degrees F.

Configuration: Pivot-bearing free in lateral axis only. Stick locked.

Objective: To feel out controls.

Thrust Duration: 42.6 seconds, stopwatch measure.

Performance: In the debriefing session, it was commonly agreed that this was the best flight accomplished to date. Lack of sufficient spring return on the throttle was considered the major control problem. Impingement of the jet blast on mud off the shoulder of the concrete was also a major problem. It was agreed that the towers should be moved to a concrete ramp.

Written postflight comments were noted as follows: ". . . pitch control was good. He should improve with experience. . . . .flights should be made over cement to prevent kicking up of soil. . . . . tethering cable was helping. . . . seems to be able to apply throttle in increments evidenced by his ability to rise from the squatting position."

The flight operator considered control, in general, to be "excellent," having most difficulty with vertical control.

Flight No. 4 January 16, 1961 Tethered Site No. 3

Outside Temperature: 37 degrees F.

Configuration: Same as No. 3, with increased spring tension on the throttle.

Objective: To feel out controls.

Performance: Operator fell backwards to sitting position upon landing. Flight was aborted due to leak resulting from impact.

Debriefing comments indicated that he had difficulty keeping his balance due to the abrupt throttle control and the throttle valve design. Tank protectors were also recommended.

Written postflight comments were noted as follows: ". . . .steam limited visibility. . . . .throttle control appeared very erratic. . . . .throttle valve seemed to stick. Temperature envelope tests may be required. . . . .a tank protector is required. . . . cannot maintain a balanced standing attitude when moving backwards on touchdown. . . . .getting up from a sitting position with this is almost impossible."

The flight operator considered control in general to be only "acceptable," having most trouble with the throttle.

Flight No. 5 January 18, 1961 Tethered Site No. 3

Outside Temperature: 21 degrees F.

Configuration: Pivot bearing free in lateral axis, grip type throttle with lighter spring than in flight No. 4, and crash protector bars at bottom of tanks.

Objective: To feel out controls.

Thrust Duration: 42.6 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that he was off the ground about two feet moving forward. It was agreed that he needed throttle practice. Some felt he needed first to learn to hover. The operator believed he was adapting to the noise and other aspects of the operation. He stated his plans to evaluate a motorcycle-type throttle and improved valve configuration.

Written postflight comments were noted as follows: ". . . .appeared as if operator was concentrating on thrust modulation. . . .seemed to have some difficulty in maintaining forward posture. . . .posture seemed difficult to maintain due to throttle valve again. . . .hovering should be attempted. . . .steam appeared 'ripe'. . . .suspect wall wash in generator---may require replacement. . . .needs practice. . . .could not seem to pick up throttle sensing. . . .it seemed to stick."

The flight operator rated his control to be "excellent" to "satisfactory," having most trouble with pitch and thrust control.

Flight No. 6 January 20, 1961 Tethered Site No. 3

Outside Temperature: 8 degrees F.

Configuration: Same as for No. 5, with reworked throttle valve (incorporating a teflon encapsulated "O" ring seal and deleted shut-off seal).

Objective: To feel out throttle control.

Thrust Duration: 37 seconds measured by stopwatch.

Performance: Debriefing comments by observers, in general, indicated that the operator was obscured by exhaust vapor and could not be seen. The flight operator also stated that he lost visual reference. There was some evidence that his confidence was increased in the throttle control.

Written comments were noted as follows:". . . .poor visibility during run. . . .operator's orientation was badly impaired by the steam. . . .gas generator appeared to operate much more efficiently indicating that the rich vapor on previous flight was due to the peroxide being cold. . . .a dense steam cloud was generated due to cold temperature. . . .seemed to have some throttle control. . . .picked himself off the ground."

The flight operator stated that he was enveloped in a cloud of vapor, losing all visual reference (the temperature was eight degrees F).

Flight No. 7 February 2, 1961 a.m. Tethered Site No. 4

NOTE: Inside temperature in the experimental hanger varies from approximately 50 to 60 degrees F.

Configuration: Motorcycle hand type throttle substituted for grip-type throttle. Both hand grips mounted top side, rather than underside, of shoulder-arm members.

NOTE: The tethering set-up in the hanger was a roller trolley mounted on a hoist track and connected to a pulley on the SRLD, which provided greater mechanical advantage to the tether men.

Objective: To feel out throttle control.

Thrust Duration: 39 seconds measured by stopwatch.

Performance: The concensus in debriefing comments was that the flight appeared excellent but he has a yaw problem in control. The motorcycle-type throttle was thought to be much superior to the grip type in performance. The twisted hemp tethering rope was thought, somewhat, to have induced yawing moments. It was also doubtful as to how much effect the tethering had on the flight.

Written comments were noted as follows:". . . .method of tethering very good. Landing appears to be most difficult. . . .tethering effects on stability are difficult to evaluate. . . .moved off course slightly. . . .had a yaw moment. . . .best flight he has had. . . . some tether help. . . .seemed at times to be off balance and would have fallen to the rear. . . .seems difficult to hold steady altitude and posture. . . .yaw seemed to be present at lift off. Tethering effects are not clearly indicated. . . .appeared to have complete and accurate control of his motions. Thrust control was a little erratic during let-down. . .amount of lift provided by tethering rope was not clear."

The flight operator rated control "excellent," having most trouble with the vertical control.

Flight No. 8 February 2, 1961 p.m. Tethered Site No. 4

Configuration: Same as flight No. 7.

Objective: To feel out general control.

Thrust Duration: 34 seconds as measured by stopwatch.

Performance: In general, debriefing comments were in effect that the flight was not as good as the morning flight. Tethering effects were thought to have been considerably reduced, and he was closer to "free" flight. The need for positive yaw control was indicated. His suit was also thought to hamper his control somewhat, and changing to a thin polyvinyl suit was suggested.

Written comments were noted as follows:". . . .a thin polyvinyl suit should be used rather than the tight one. . . .tethering rope crossing over could be responsible for instability. . . .did not have control he had on previous flight. . . .tethering rope allowed more slack this time. Controllability did not appear as good as flight No. 7. . . .yaw problem interfered with attaining mission objectives. . . .didn't seem as good as previous run. . . .very good control. . . .tendency to yaw in hovering when the rope was slack. . . .needs positive yaw control. . . .appeared to lose confidence after first attempt to rise. . . .also a yaw tendency. . . . Pushing the flights to meet schedules will cause difficulty. . . . inadvertent yaw moments seemed to result from the rope. There seemed to be less help from tethering and vertical control seemed poorer. . . .legs seemed to swing.

The flight operator rated control "satisfactory" to "excellent," having most difficulty in translation and vertical control.

Flight No. 9 February 3, 1961 Tethered Site No. 4

Configuration: Same as previous flight No. 8.

NOTE: The tethering rope was changed from a twisted manila rope to a braided polyethylene. A thin polyvinyl suit, i.e., a normal propellant-handler's protective suit, was also worn by the operator initially on this flight.

Objective: To determine ability to translate without yaw.

Thrust Duration: 30 seconds measured by stopwatch.

Performance: The consensus in debriefing was that he still picked up considerable yawing motion and needed positive yaw control.

Written comments were noted as follows:". . . .crossover and rotation of flyer should be eliminated. . . .Lateral oscillations developed during hover, which converted into yaw spin. The operator needs yaw control. . . .on all but first attempt the operator had yaw problems. He was actually free from tether on the second flight. Good control. . . .Flight was good except for spin. He was on his own 90 percent of the time. . . .developed spinning motion on the first attempt. . . .appeared to have good control . . . .legs seemed to swing in pendulum fashion. . . .seemed to have yaw-roll coupling problem. . . .lateral oscillations developed in which yaw coupling occurred."

The flight operator stated that he began spinning, and, in this configuration, had no yaw control to stop it.

Flight No. 10 February 6, 1961 Tethered Site No. 4

Configuration: Same as previous flight.

Objective: To determine ability to translate and hover without yaw.

Thrust Duration: 30.6 seconds as measured by stopwatch.

Performance: In debriefing, the maximum altitude of the flight was estimated to be approximately three feet. The flight, in general, was considered to be "good" although he picked up uncontrollable oscillations in yaw. The operator also reported intense electrical shocks occurring a the ear and throttle hand.

Written comments were noted as follows:". . . .good forward control on first flight. . . .attained a maximum elevation of about three feet off the floor. . . .developed a clockwise spinning motion. Rate of oscillations seemed to increase until he cut his power. . . .seemed to have most trouble in braking. Tethering was not clearly indicated as to whether flight was free. Posture seemed unsure. . . .best run to date. Twirling at end of first attempt appeared to be definitely induced by tethering. . . .yaw is still problematical. . . .seemed to have good control. He was free most of the time."

The flight operator rated control as "good", stating that this was the first time he was able to stop, turn around in mid-air and go in the opposite direction.

Flight No. 11 February 8, 1961 a.m. Tethered Site No. 4

Configuration: A spherical-pivot bearing was installed in the SRLD, permitting freedom in the roll and pitch axes.

Objective: To explore the action of the pitch-axis bearing in translation and hovering.

Thrust Duration: 35 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that a major yaw problem was still evident. The highest altitude achieved to date was noted, approximately 15 feet. The operator felt confident in his pitch control. He felt his let-down control to be jerky and unsteady. He feels it will improve with practice.

Written comments were noted as follows:". . . .ground wire should be installed if possible. . . .good control in flight. No control on landing. . . .reached an altitude of about 15 feet; hovered for a time. . . .then a yaw-roll oscillation developed . . . .flight looked very good. . . .legs seemed to flail slightly. Lost control in mid-air. Inadvertently turned in hovering. . . .reached an altitude of approximately ten feet and maintained good control during ascent. Began clockwise spinning at altitude inducing pronounced circular oscillation. Began to set down and tethering took over and he shut off his power completely. . . .control was good. . . .needs control to stop spinning . . . .developed yaw and roll coupling during hover."

The flight operator stated that this was the first time he was able to hover, and at the highest self-sustained altitude of 15 to 20 feet.

Flight No. 12 February 8, 1961 p.m. Tethered Site No. 4

Configuration: Left hand nozzle was adjusted forward 1/2 degree to compensate for inadvertent yawing observed on previous flights. Other than this, configuration was the same as previous flight.

Objective: To explore further control in hovering and translation and practice let-down control.

Thrust Duration: 31 seconds as measured by stopwatch.

Performance: In debriefing comments, it was agreed that the nozzle compensation in yaw was too severe and yaw-spin occurred in the opposite direction. Legs flailing in a pendulous fashion was also described.

Written comments were noted as follows:". . . .flight not as good as previous flight. . . .should put nozzles back to neutral and get some yaw control in the system. . . .needs yaw control. . . .the yaw adjustment on the nozzles was too much. He rotated in the opposite direction (CCW). . . .legs and feet flailed. Helmet seemed to be hitting shoulder rings, yaw and roll coupling occurred. The fix on nozzles caused spin in opposite direction. . . .the one-half degree change in nozzle incidence was too much because this time he yawed to the left. . . .1/4 degree should be enough. Pitch and roll control during hovering was fair."

The flight operator rated the flight only "good" to "acceptable," and stated that it was worse than the morning flight.

Flight No. 13 February 10, 1961 Tethered Site No. 4

Configuration: A yaw control, providing 2/3 degree differential deflection of nozzles, was incorporated for left-hand stick control.

Objective: To test for yaw control.

Thrust Duration: 31 seconds as measured by stopwatch.

Performance: Debriefing comments, in general, indicated that over control in yaw appeared to be operating.

Postflight written comments were noted as follows:". . . .did not appear to have (or use) yaw control. Motions were erratic. . . not nearly as good as many previous flights. . . .needs two-hand coordination practice. . . .had some yaw control but not enough . . . .legs seemed to flail. . . .needs more yaw control."

The flight operator rated the flight from "good" to "marginal." He stated that yaw control was insufficient, and more than 2/3 degree of nozzle deflection was required.

Flight No. 14 February 13, 1961 a.m. Tethered Site No. 4

Configuration: Left-hand yaw control was modified to provide a total of 3 degrees deflection each nozzle (1-1/2 degrees was used on previous flight).

Objective: To feel out yaw control.

Thrust Duration: 30 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that the operator seemed to be over-controlling in yaw, and that there was complete loss of control.

Written comments were noted as follows:". . . .seemed to lose yaw control completely. . . .coupling occurred in pitch and roll . . . .legs swung. . . . suggest reducing control level in yaw . . . .corrective actions attempted may have introduced instability. . . .lost all control. . . .too much yaw control. . . .could not recover from over-control. . . .unable to stabilize. . . .reached an altitude of approximately ten or twelve feet. . . .suggest swivel in line to prevent binding. . . .tethering saved him."

The flight operator rated performance from "good" to "impossible" (yaw and coupling), and noted that he noticed yaw and roll cross coupling for the first time.

Flight No. 15 February 13, 1961 p.m. Tethered Site No. 4

Configuration: Yaw control was reduced to a total of 1-1/2 degrees each nozzle.

Objective: To feel out yaw control.

Thrust Duration: 30 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that the yaw control problem was less severe, but yaw was still a problem.

Written comments were noted as follows:". . . .controlled azimuth well, due to good leg control and low control level. . . .suggest some way be provided to keep his legs out of the jet stream. . . . slow turn was encountered and was out of control. . . .traveled backwards. . . .yawing moments developed that appeared to be out of control. . . .no adverse effects appeared to be induced by the tethering rig. . . .nozzle control should be more sensitive . . . .1-1/2 degree-range appears adequate. . . .more stable than previous run. . . .yaw slight with fair control. . . .legs seemed to flail possibly from moments induced by trolley."

The flight operator rated the flight from "good" to "satisfactory," noting that he tried to raise his legs somewhat to keep his feet out of the jets.

Flight No. 16 February 14, 1961 a.m. Tethered Site No. 4

Configuration: Yaw control deflection increased to one degree fore and aft, each nozzle.

Objective: To feel out yaw control.

Thrust Duration: 28 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that yawing control appeared to be improved, but that improved design and practice were still required. An appreciable lag in yaw response was also suggested.

Written comments were noted as follows:". . .yaw control seemed poor because of no centering spring. . . .leg swinging on forward flight. . . .needs practice in yaw. . . .leg movements induce control problems. . . .can see lag in the control."

The flight operator rated all parameters "excellent," but yaw only satisfactory. He noted that yaw control was still sluggish.

Flight No. 17 February 14, 1961 p.m. Tethered Site No. 4

Configuration: Same as Run No. 16.

Objective: To feel out yaw control.

Thrust Duration: 30 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that yaw control was still difficult, and improvement was required.

Written comments were noted as follows:". . . .did well in forward flight. . . .yaw control was improved but not satisfactory. . . .landing not satisfactory. . . .moved his legs more than on previous flights. . . .fairly good control. . . .yaw is working but slow. . . . still does not seem able to control yaw. . . .had trouble in throttle control also."

The flight operator rated control "good" and "excellent," but noted yaw control was insufficient.

Flight No. 18 February 15. 1961 Tethered Site No. 4

Configuration: Thrust nozzles were deflected five degrees laterally each side. Two degrees maximum yaw deflection was still available as on the previous flight.

Objective: To test for yaw control.

Thrust Duration: 29 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that the feet now seemed free of the jet blast and flailing of the legs seemed less likely. Yaw control was still not acceptable.

Written comments were noted as follows:" . . .much time and propellants are being used in correction rather than towards flight objective. . . .when he went unstable it was due mostly to taking up too much slack on the rope too fast.. . .needs more landing practice. . . .yaw reacted sluggish. . . .legs spread out under tether on landing."

The flight operator rated all parameters but yaw "good" or "excellent." He noted that yaw control was insufficient as yet; the nozzles' being canted outward five degrees improved the configuration, since no leg-jet interference was apparent and stability and control appeared as good or better.

Flight No. 19 February 16, 1961 Tethered Site No. 4

Configuration: Same as previous flight.

Objective: To feel out yaw control.

Thrust Duration: 25 seconds as measured by stopwatch.

Performance: Debriefing comments indicated that the flight was, in general, a poor one, and that yaw accelerations were uncorrectable with this configuration.

Written comments were noted as follows:". . . .exhibited instability in legs. . . .not able to hold altitude. . . .yaw control still a problem. . . .pilot may become overconfident from his initial smooth take-off and think he can do more than he is capable of doing--he seemed surprised when erratic motions occurred. . . .controlled feet well on early attempts-then began to flop. . . .noticed a full yaw motion at one time that had little or no corrective effect. . . yaw control poor. . . .slight power problem causing erratic climb. . . .body motion causing spin. . . .yaw control poor. . . .not enough height. . . .picked up yaw moments in all attempts."

The flight operator rated flight parameters from "excellent" to "marginal," and noted that yaw control was still a problem.

Flight No. 20 — February 17, 1961 — Tethered Site No. 4

Configuration: Same as previous flight.

Objective: To feel out yaw control.

Thrust Duration: Not obtained.

Performance: Debriefing comments indicated that performance was much improved over the previous flight, but that the operator went out of control due to the tethering line. Also, injury was incurred due to breaking of the tethering line.

Written comments were noted as follows:". . . .tethering control was lost - may have been due to second trolley control rope. . . . control rope broke. . . .operator picked up translation. . . .flight characteristics looked pretty good. . . .seemed to get erratic and into a horizontal position with his left side down when he dropped . . . .total fall estimated to be about eight feet. . . .vertical control was good until he dove and got a tether rope jerk which started his trouble sequence. . . .tether rope is not strong enough, should be tested periodically. . . .more captive tests should be done before free flight."

The first flight operator discontinued his flight testing after he had incurred injury. Upon inspection of the various indices employed for performance evaluation, i.e., the rating charts, no clear-cut quantitative evidence of learning was apparent. General observation did, however, strongly suggest that the operator was improving in his general motor performance. Further, it was noted that the stopwatch measurement was obtained as a response to the noise-signal duration-to-propellant-exhaustion. This meant that any burst at all was recorded as time. Therefore, with decreasing time, the operator was applying increased thrust volume, which meant that he was approaching or sustaining an airborne condition with greater frequency. Figure 28 presents a plot of this duration against run number, which does suggest that learning was emphatically occurring with the first flight operator.

Following injury to Flight Operator Moore in his Flight No. 20, a Second Flight Operator was employed for Flight Tests. Alternating personnel and revised procedures are presented in Appendix I, at Tethered Site No. 4.

Flight Operator Graham completed five exploratory flights, with the objective being to obtain general familiarity with the rig and tethering system. Flight of this second Flight Operator began on March 1, 1961. His five general exploratory flights were completed on March 6.

In these early flights, Operator Graham described his experience as novel - as though he were being picked up by a hook. He felt that he was "flopping" around quite a bit, and seemed most concerned about pitch control. A kind of skating-like leg motion, of which for the most part he was not aware, seemed to be an element of motor skill transferred from his skating proficiency. (Operator Graham plays amateur hockey and has ice skated since he was eight years old.) This "skating" behavior in general, seemed to facilitate his early learning, for he seemed largely to maintain equilibrium and an upright position independent of the tether. Later, however, there appeared to be some interference, insomuch as he had to concentrate on holding his legs steady.

Beginning on March 7, Operator Graham attempted a translation task, with the objective being to fly down range approximately 50 feet, and to set down on a target approximately 4 feet square. . His performance on all subsequent tethered flights as well as free flights is summarized below.

Flight No. 6 March 7, 1961 a.m. Tethered Site No. 4

Configuration: Return spring installed in throttle; nozzle two-degree yaw deflection for left-hand control; spherical pivot bearing for motion in pitch and lateral axis.

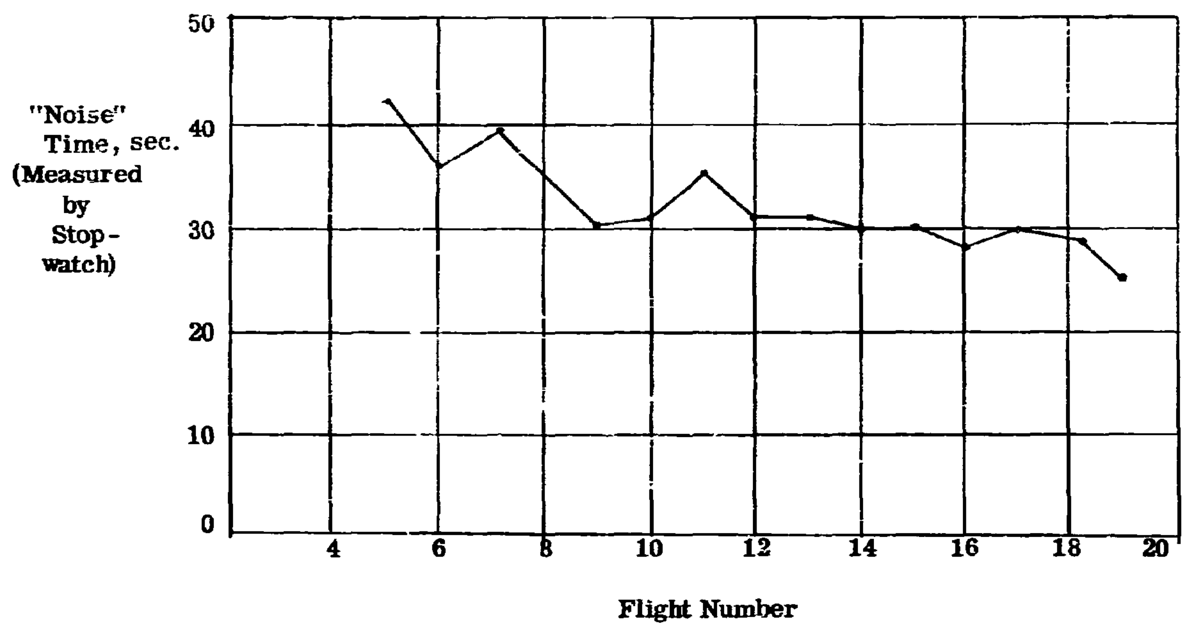


Figure 28. First-Operator Learning as a Function of "Noise-Time" Decrease

Estimated Miss Distance in Range: 8 feet approximately.

Performance: The operator made two tries from the starting position, and one back. He overshot on the first trial and picked up a spin. On the second attempt he overshot. Tethering appeared to be well controlled. The operator stated that he encountered a yaw problem for the first time.

Flight No. 7 March 7, 1961 p.m. Tethered Site No. 4

Configuration: Same as previous.

Estimated Miss Distance: 10 ft. approximately.

Performance: The operator picked up a lateral moment on the first attempt, was snubbed and set down. He completed the first try and set down about the target in a walking motion. Tethering appeared to be well controlled. The flight operator stated that he was becoming more confident, and was beginning to concentrate on his leg posture.

Flight No. 8 March 8, 1961 Tethered Site No. 4

Configuration: Same as previous.

Estimated Miss Distance: 5 ft approximately.

Performance: An altitude barrier consisting of a light string was set up in the operator's flight path. On the initial blast off he set back down, then off again, barely cleared it. He made a total of three tries. Tethering appeared to be well controlled. The operator stated that his ability to control the vehicle had appreciably increased.

Flight No. 9 March 9, 1961 Tethered Site No. 4

Configuration: Same as previous.

Objective: To translate down range 50 feet between 4-foot square targets (yellow paint). An 18-inch high altitude barrier was also set up.

Thrust Duration: 22 seconds.

NOTE: Time measure was obtained in this case from throttle timer, actuated at 70 percent thrust.

Performance: The operator made four attempts. On the second and third, he accomplished his objective within 3 to 4 feet. Spinning seemed to be a major problem. The flight operator stated that he had most difficulty with yaw and let-down control.

Flight No. 10 March 10, 1961 Tethered Site No. 4

Configuration: Throttle return spring was removed upon advice of Stability-and-Control Group.

Objective: To translate down range 50 feet between targets (no altitude barrier) and turn in controlled yaw.

Thrust Duration: 25 seconds.

Performance: Four attempts were made. The closest he came to target was approximately 12 feet. Translation rate appeared good. Uncontrolled spin was a major difficulty. The operator felt that yawing was the major problem, and that over control or ground wash effects on his legs may have been responsible.

Flight No. 11 March 13, 1961 Tethered Site No. 4

Configuration: Same as previous flight.

Objective: To translate down range 50 feet between targets, hold altitude, turn and set down.

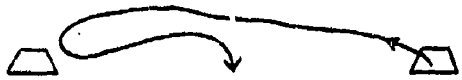
Thrust Duration: 25 seconds.

Performance: Operator did not effectively accomplish translation. He rather attempted to hover. He managed to reverse direction of spin in yaw control. The flight operator considered the flight successful, since he was able to accomplish hovering.

Flight No. 12 March 14, 1961 Tethered Site No. 4

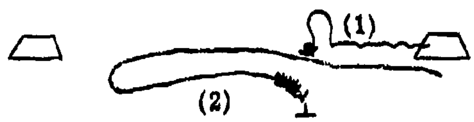
Configuration: Same as previous flight.

Objective: To translate down range 50 feet, hold altitude, turn and return to mid-point between targets.



Thrust Duration: 25 seconds

Performance: Two attempts were made as follows:

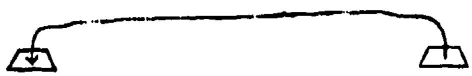


Pitch translation rate and braking, and yaw control were major problems. The flight operator stated that major problem was in loss of throttle control reference.

Flight No. 13 March 15, 1961 Tethered Site No. 4

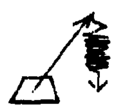
Configuration: Same as previous flight.

Objective: Translate and attempt to maintain constant altitude, go slow and land.



Thrust Duration: 22 seconds.

Performance: Made four attempts. On the third attempt he succeeded.

(1)  8 - 10 feet altitude

(2) 3 - 4 feet altitude

(3)

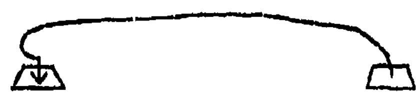
(4)

Major difficulty appeared to be in initial pitch control being back off center. Some yaw control appeared effective, but spinning occurred. Throttle control (direction) was momentarily lost. The flight operator called for replacement of the return spring in the throttle.

Flight No. 14 March 16, 1961 a.m. Tethered Site No. 4

Configuration: Throttle return spring was replaced due to operator having lost control-direction reference on previous flight.

Objective: To translate and turn for touchdown as follows:



Thrust Duration: 17 seconds.

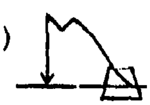
Performance: Five attempts were made as follows:

(1)

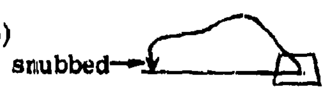
(2)

(3)

(4)



(5)

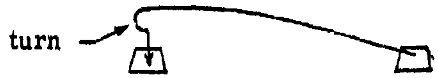


Major difficulty appeared to be in spinning and pitch control for translation. The flight operator considered yaw to be the major control problem.

Flight No. 15 March 16, 1961 p.m. Tethered Site No. 4

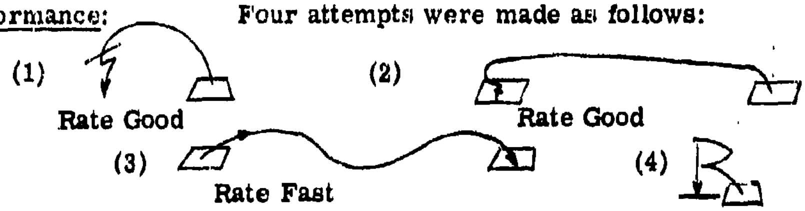
Configuration: Same as previous flight.

Objective: To translate as follows:



Duration: 23 seconds.

Performance: Four attempts were made as follows:



Braking in flight appeared to be a major problem. The flight operator stated that he had no yaw problem but still considered this most difficult.

Flight No. 16 March 17, 1961 a.m. Tethered Site No. 4

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 27 seconds.

Performance: The operator accomplished translation to target, and was able to correct for yaw in translation. Rate was good. The flight operator stated that take-off control was difficult on the first try.

Flight No. 17 March 17, 1961 p.m. Tethered Site No. 4

Configuration: Same as previous flight.

Objective: Same as previous flight

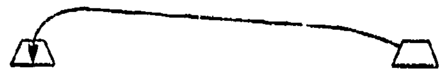
Thrust Duration: 25 seconds.

Performance: Translation was too fast. He picked up yawing; flight was erratic and he was frequently snubbed by the tether. The operator considered lateral and yaw control coupling to be the major problem.

Flight No. 18 — March 21, 1961 a.m. (1st) Tethered Site No. 4

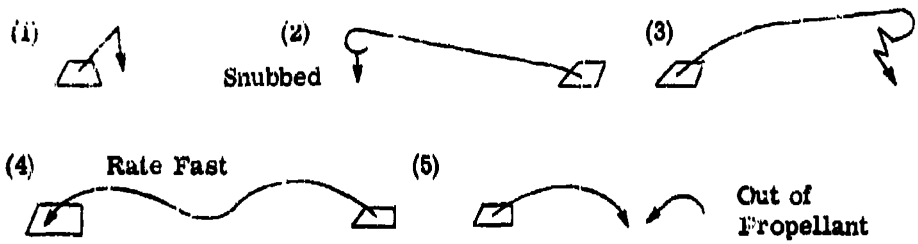
Configuration: Same as previous flight.

Objective: Straight and level translation as follows:



Thrust Duration: 26 seconds.

Performance: Five attempts were made as follows:

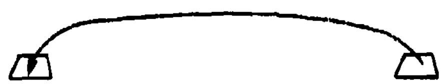


Major problem was yaw skewing. Tether trolley appeared to interfere. The operator described overcontrol in yaw to be problematic.

Flight No. 19 — March 21, 1961 a.m. (2nd) Tethered Site No. 4

Configuration: Same as previous flight.

Objective: To translate at 6 - 10 feet altitude as follows:



Thrust Duration: 20 seconds.

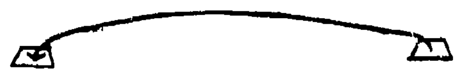
Performance: Three attempts were made as follows:

The major problem seemed still to control forward angle at take off. Second tether trolley control was reported difficult when operator was hovering. The operator believed yaw and lateral control to be his major difficulty.

Flight No. 20 March 27, 1961 p.m. Tethered Site No. 4

Configuration: Kinesthetic control (pivot) bearing was locked. Control available by stick motion only. Linkages were connected to actuate nozzles in three axes as follows: (a) three degrees laterally outboard each side of five degrees of cant; (b) total travel of 9 degrees of pitch; (c) total differential in yaw control of 18 degrees. The task became two-hand coordination, with right-hand throttle control and left-hand flight control.

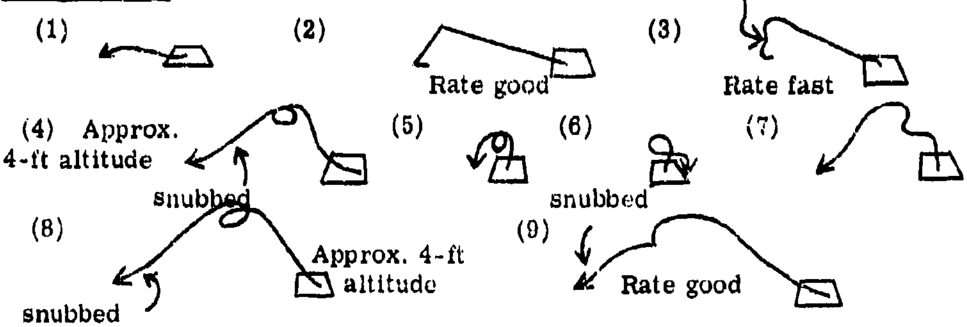
Objective: To check out hand controller in translation task, stay low and translate between targets as follows:



NOTE: Stick control linkages were inadvertently reversed in set-up of nozzles in pitch, resulting in reverse control direction. This was discovered in preflight checks, and the flight plan was subsequently changed to a general exploratory task.

Thrust Duration: 27 seconds.

Performance:

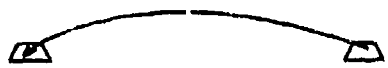


The operator's balance forward seemed to be the major problem, with yaw control much too sensitive. The operator felt that he could not evaluate this type of control since he had no feel for it.

Flight No. 21 March 30, 1961 a.m. Tethered Site No. 4

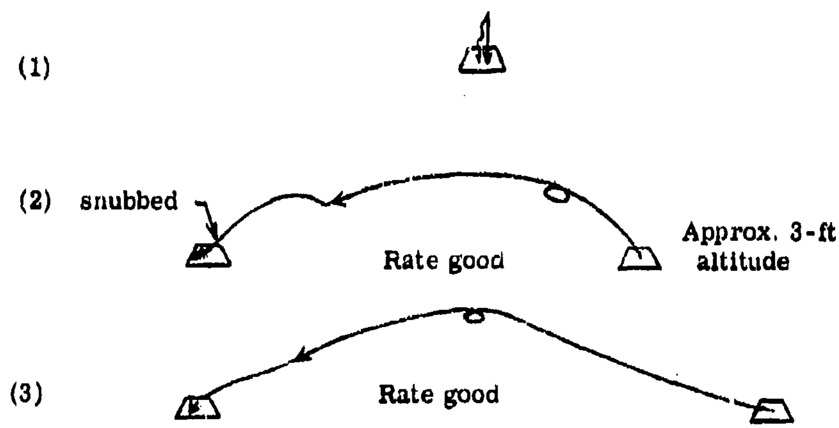
Configuration: Stick direction for pitch control linkages was corrected. Total nozzle travel in pitch was reduced to five degrees, and yaw with a total differential of six degrees. Lateral nozzle deflection remained unchanged. An abdominal support plate was also installed.

Objective: To check out hand controller in translation task.

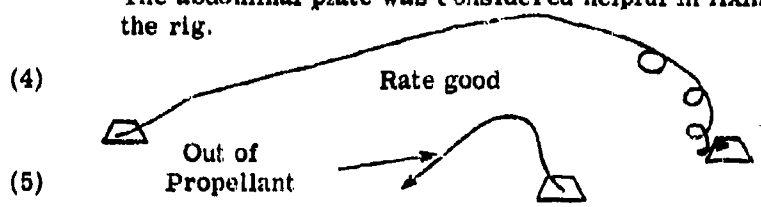


Thrust Duration: 26 seconds.

Performance: Five attempts were made as follows:



Major problem appeared to be in side slip and too much yaw control. The operator was still most concerned about yaw control. The abdominal plate was considered helpful in fixing his torso in the rig.



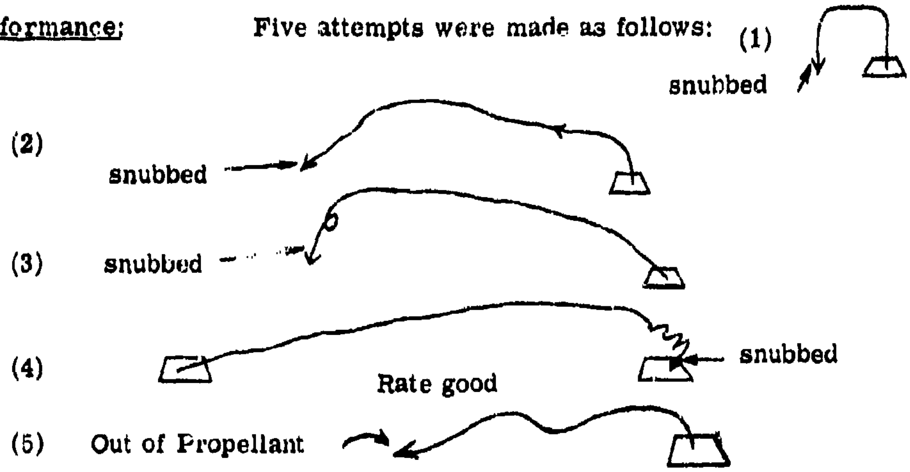
Flight No. 22 — March 30, 1961 p.m. — Tethered Site No. 4

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 26 seconds.

Performance: Five attempts were made as follows:



Major problem seemed still to be side slippage and yaw control (he translated rearward). He appeared also initially to be back off balance. The flight operator considered side slippage problematic.

NOTE: Beginning with the following flights (Operator Graham's flight number 23), the SRLD configuration was established, and, except for minor adjustments, remained unchanged, i.e., the operator performed with the same essential configuration for continued skill acquisition. The configuration was as follows:

Fitting: (1) Additional padding provided about lifting rings to distribute lifting pressure about axillae.

(2) Semicircular strips installed inside corset extruding into the pelvic region below iliac crest fitted with safety belt; second safety belt holding large abdominal plate firmly against abdomen. These effectively served to immobilize upper torso.

Control: (1) Spherical bearing for pivoting thrust fore and aft in pitch, and laterally in roll.

(2) Spring-loaded left-hand yaw control actuating jetavators about fixed nozzles.

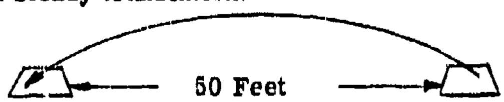
(3) Spring-loaded right-hand throttle control.

Fourteen additional tethered flights were completed with this configuration in the experimental hangar (a total of 36 tethered flights for operator Graham). Free-flight testing was begun on April 20th. The first flight was performed over the grass on Niagara Falls Airport near the threshold of Runway 32. Appendix I describes the free-flight sites employed and the general procedural checklist followed.

Flight No. 23 April 7, 1961 p.m. Tethered Site No. 4

Configuration: Corset, arm-ring, and abdomen plate modifications; spherical pivot bearing free; left-hand stick control in yaw, actuating jetavators only.

Objective: To feel out effectiveness of jetavators; execute straight and steady translation.



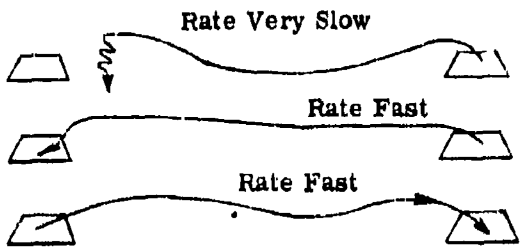
Thrust Duration: 27 seconds.

Performance: Three attempts were made as follows:

snubbed (1)

snubbed (2)

(3)



Major problem was described as an inadvertent and uncontrolled lateral shift. The operator described the new configuration as much firmer, more stable and less touchy. Yaw control, he described also, as less touchy.

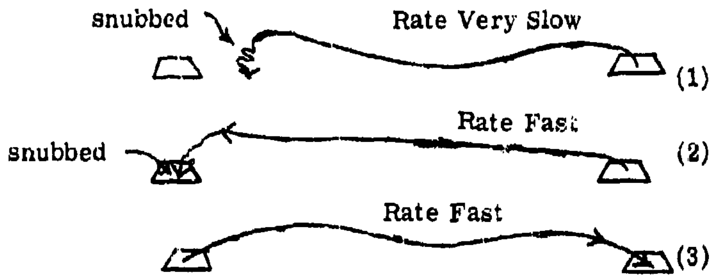
Flight No. 24 April 7, 1961 p.m. Tethered Site No. 4

Configuration: Same as previous flight.

Objective: Practice and control evaluation; plan as previous flight.

Thrust Duration: 28 seconds.

Performance: Three attempts were made:



Major problem appeared to be lateral drift. The operator described the rig as firm in stability with yaw control movements becoming automatic.

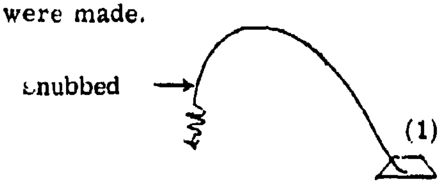
Flight No. 25 April 10, 1961 a.m. Tethered Site No. 4

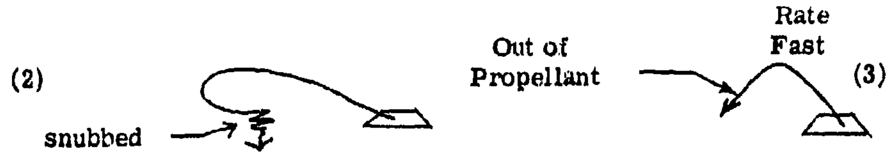
Configuration: Same as previous flight.

Objective: To evaluate control in hovering and turning.

Thrust Duration: 25 seconds.

Performance: Three attempts were made.



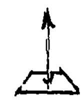


The operator stated that he had a great deal of confidence with this configuration.

<u>Flight No. 26</u> April 10, 1961 p.m. Tethered Site No. 4

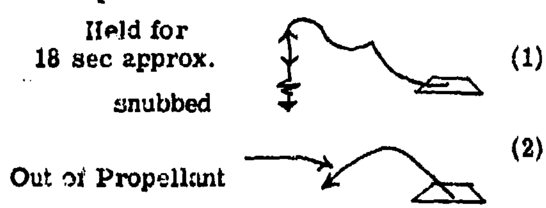
<u>Configuration:</u> Same as previous flight.

<u>Objective:</u> To test for straight and steady hovering control.



<u>Thrust Duration:</u> 25 seconds.

<u>Performance:</u> Two attempts were made:



Major problem appeared to be yaw control, which the operator felt would improve with experience. The operator felt that he could have done better, particularly in controlling yaw.

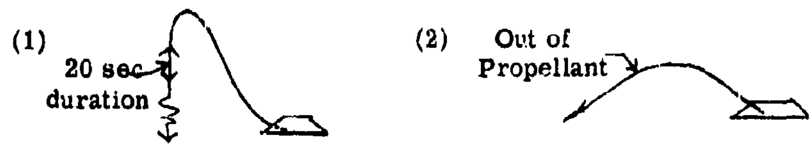
<u>Flight No. 27</u> April 11, 1961 a.m. Tethered Site No. 4

<u>Configuration:</u> Same as previous flight.

<u>Objective:</u> Same as previous flight.

<u>Thrust Duration</u> Not obtained.

Performance: Two attempts were made:



Yaw control seemed still to be a major control problem. The operator noted that lateral motion was deliberately controlled effectively.

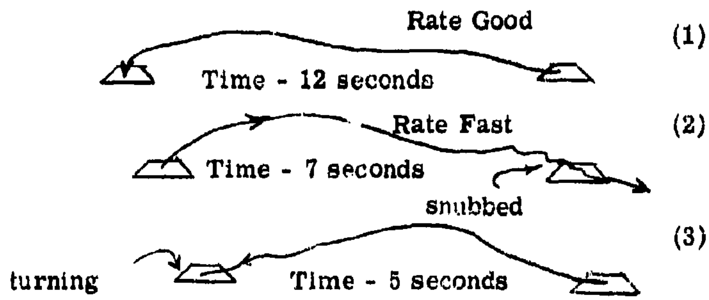
Flight No. 28 April 11, 1961 a.m. Tethered Site No. 4

Configuration: Same as previous flight.

Objective: To translate, and hold steady for let-down.

Thrust Duration: 28 seconds.

Performance: Three attempts were made:

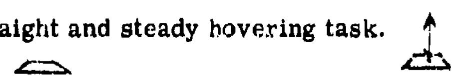


The operator felt that he was controlling the flight independent of the tether.

Flight No. 29 April 14, 1961 p.m. Tethered Site No. 4

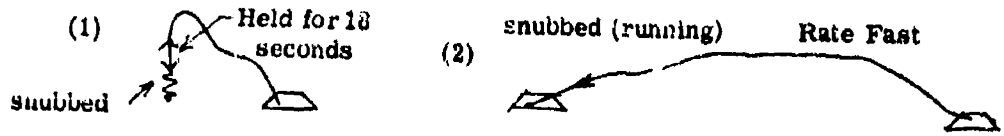
Configuration: Throttle detent incorporated at 70 percent thrust; throttle friction reduced; valve replaced.

Objective: Perform straight and steady hovering task.



Thrust Duration: 28 seconds.

Performance: Two attempts were made, the second being translation:

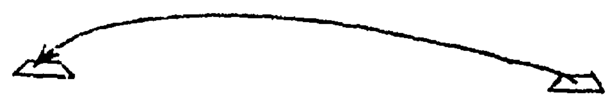


The operator stated that there was no noticeable improvement with throttle detent, and the rig felt exceptionally stable.

Flight No. 30 April 14, 1961 p.m. Tethered Site No. 4

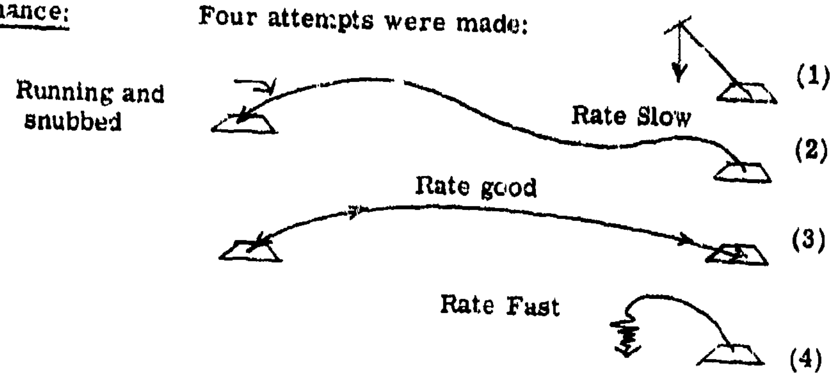
Configuration: Same as previous flight.

Objective: Straight and steady translation.



Thrust Duration: 27 seconds.

Performance: Four attempts were made:

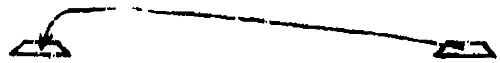


The operator felt that initial lift-off was sluggish.

Flight No. 31 | April 14, 1961 p.m. | Tethered Site No. 4

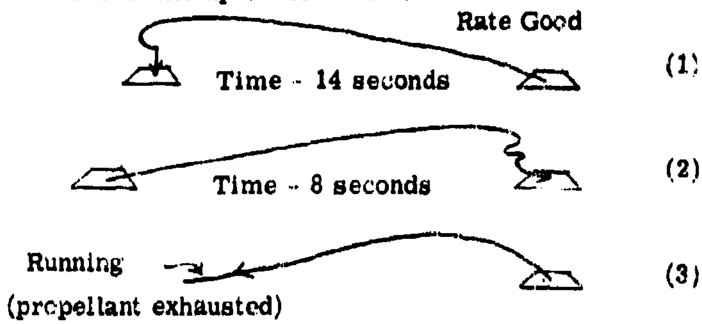
Configuration: Same as previous flight.

Objective: To continue series of translations for proficiency leading to free flight.



Thrust Duration: 25 seconds.

Performance: Three attempts were made:



The operator considered control easy and smooth.

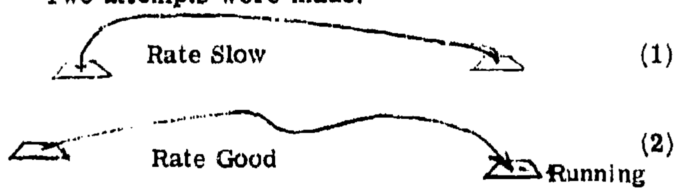
Flight No. 32 | April 17, 1961 p.m. | Tethered Site No. 4

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 24 seconds

Performance: Two attempts were made:



The operator dithered lateral control and considered it easy.

Flight No. 33 April 18, 1961 a.m. **Tethered Site No. 4**

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 23 seconds.

Performance: Two attempts were made:

(1)

(2)

No tethering control was necessary. The operator felt that the flight was well controlled.

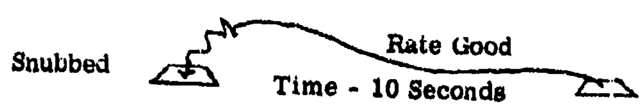
Flight No. 34 April 18, 1961 a.m. Tethered Site No. 4

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 19 seconds.

Performance: Two attempts were made:



(1)

(2)

On the first attempt, the operator "dithered" lateral control and required snubbing. He felt that he still had to "feel out" the controls.

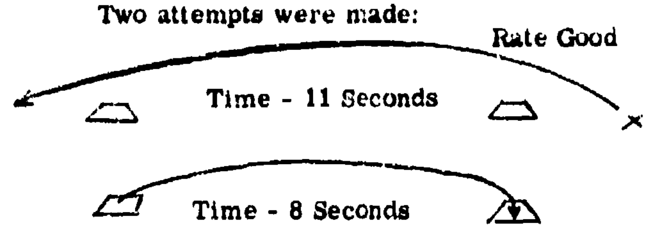
Flight No. 35	April 19, 1961 a.m.	Tethered Site No. 4

Configuration: Same as previous flight.

Objective: To perform longer-range translation (100 ft approx.) to prepare for free flight.

Thrust Duration: 23 seconds.

Performance: Two attempts were made:



(1)

(2)

No tethering control was necessary, The operator considered the flights well controlled.

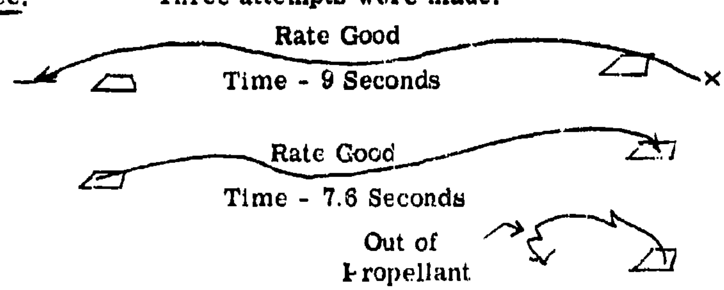
Flight No. 36	April 19, 1961 a.m.	Tethered Site No. 4

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 27 seconds.

Performance: Three attempts were made:



(1)

(2)

(3)

No tethering control was necessary. The operator considered that a stable,safe flight had been demonstrated.

Free-Flight No. 1(37) April 20, 1961 a.m. Free Site No. 1 (Appendix I)

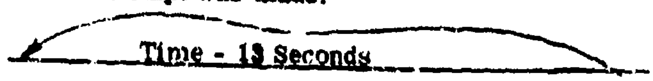
NOTE: Number in parentheses indicates total number of Operator Graham's flights, both tethered and free flight.

Configuration: Tethering brackets removed from rig.

Objective: To translate straight and steady in free flight 100 feet.

Thrust Duration: 16-1/2 seconds.

Performance: One attempt was made:



Steam generated tended to obscure visual contact but the operator moved out of it in translation (temperature was 35 degrees F). The operator felt high-level confidence in his control.

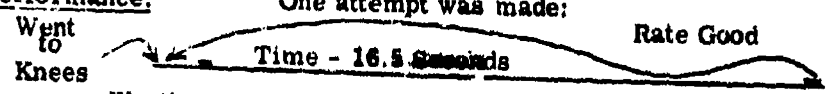
Free-Flight No. 2 (38) April 21, 1961 a.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 18 seconds.

Performance: One attempt was made:



Weather was inclement, precipitating with wind gusts up to 25 MPH from the SSW. Steam was generated but seemed not appreciably to interfere with the operator's vision. The operator described deliberate altitude control to be his major problem.

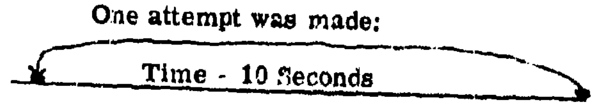
Free-Flight No. 3 (39) April 24, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: Extended range translation (150 feet)

Thrust Duration: 12 seconds.

Performance: One attempt was made:



Impingement bothered operator, who requested goggles for further flights. Temperature was 60 degrees F; wind from the WNW at 5 MPH. The operator still felt altitude to be his major problem, i.e., "willful" ascent.

Free-Flight No. 4 (40)   April 24, 1961 p.m.   Free Site No. 2

Configuration.   Same as previous flight, goggles were provided to protect operator from impingement effects.

Objective: Same as previous flight.

Thrust Duration: 13 seconds.

Performance: One attempt was made:

Major problem was an induced yaw which necessitated let-down Goggles were also not adequate and steamed up. Temperature was 54 degrees F. Wind was from the NE at 10 MPH. The operator described inadvertent yawing to be the major problem.

Free-Flight No. 5 (41)   April 25, 1961 p.m.   Free Site No. 2

Configuration: Same as previous flight.

Objective: To determine maximum range capabilities in translation.

Thrust Duration: 18 seconds.

Performance: Three attempts were made. The first, for three seconds, resulted in excessive acceleration,and let-down was made. The second, for five seconds, was stopped due to the wind blowing steam into the operator's flight path and obscuring vision. On the third attempt, the operator translated approximately 150 feet. The operator described velocity control as the major problem.

Free-Flight No. 6 (42)   April 26, 1961 a.m.   Free Site No. 2

Configuration: Same as previous flight.

Objective: Same as previous flight.

Thrust Duration: 18 seconds.

Performance: Two attempts were made. The first covered approximately 90 feet, but at too rapid an acceleration, and set-down was accomplished. The operator let-down, falling to his knees to absorb the shock. The second was 100-foot translation in a walking landing. Steam was severed but the treated goggles were adequate. Temperature was 42 degrees F; wind was from the WNW at 18 MPH. Relative humidity was 79 percent. The operator described velocity control as the major problem.

Free-Flight No. 7 (43) April 26, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To Test for hovering and stability control.

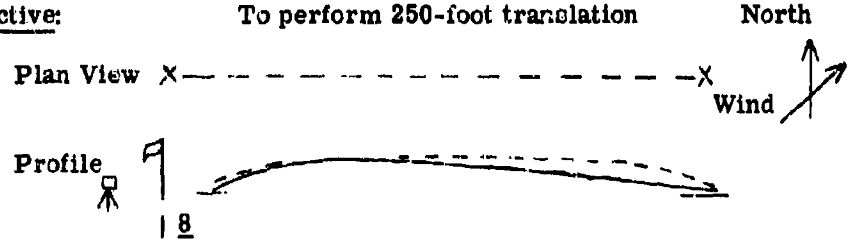
Thrust Duration: 16 seconds.

Performance: A rise to 4-foot elevation was accomplished in 50-foot translation. Altitude was held for approximately 10 seconds; let-down, control, and balance were lost at approximately 2 feet. No injury was sustained. Vision was somewhat hampered by exhaust steam generated. The temperature was 45 degrees F; wind from the WNW with gusts up to 34 MPH. Relative humidity was 84 percent. The operator described throttle cutback as the major difficulty, having fallen to the ground.

Free-Flight No. 8 (44) April 27, 1961 a.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To perform 250-foot translation



Thrust Duration: 19 seconds (as measured by throttle timer)

Temperature: 56 degrees F

Relative Humidity: 59 percent

Duration (as measured by stopwatch)

Burst: 0.7 sec.

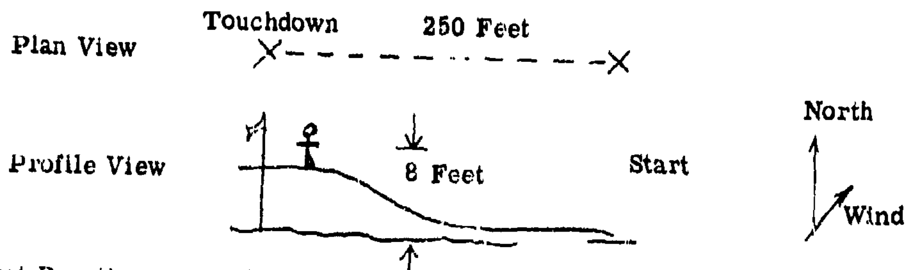
Flight: 18.2 sec.

Performance: A flag was placed 9 feet above ground for reference. Control appeared good all the way - started yaw spin approximately half way, and cancelled it smoothly. Operator was not aware of yaw control. He saw the flag only intermittently, looking down most of the time. The flight operator considered the flight "good", being most concerned about propellant expenditure.

Free-Flight No. 9 (45) April 27, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To fly to flag, and hover with eyes level at flag.



Thrust Duration: 15 seconds.

Temperature: 56 degrees F.

Relative Humidity: 59 percent

Wind: SW at 10 mph

Time (as measured by stopwatch)

Burst: 0.7

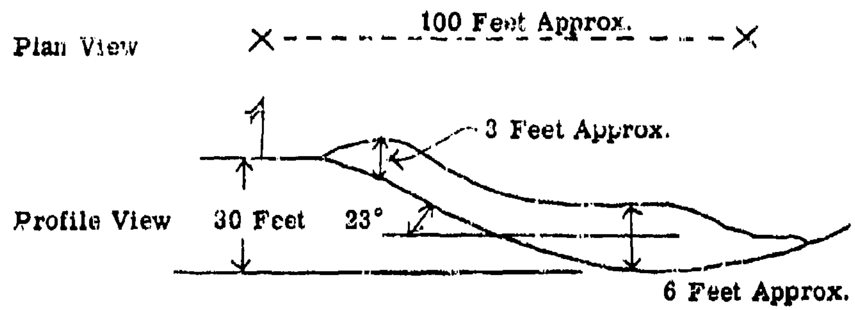
Flight: 13.7

Performance: Lift off was slow, moved slowly to a point near flag, and yawed slowly 90 degrees till facing flag; hovered with eyes level just above flag and developed a slow backward translation just prior to let-down. Control appeared good, except during let-down which was rather rapid. Operator did not fall. He considered the flight as evidence of good hovering control.

Free-Flight No. 10 (46) May 1, 1961 a.m. Free Site No. 3 (Appendix I)

Configuration: Same as previous flight.

Objective: To fly up a hill parallel to the slope.



Thrust Duration: 15.5 seconds.

Temperature: 55 degrees F

Relative Humidity: 95 percent

Time (as measured by stopwatch)

Burst: 1.0 sec
Flight: 13.8 sec

Performance: Lift off was slow; then climbed steeply, after which he flew parallel to slope up to the crest. The operator described his major concern to be in propellant exhaustion.

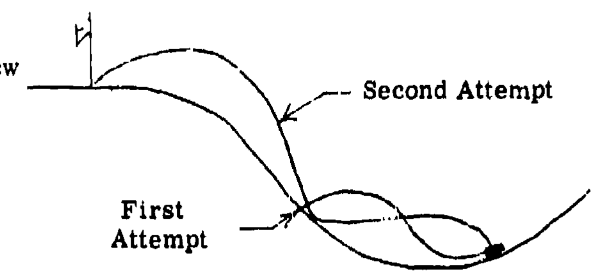
Free-Flight No. 11 (47) May 1, 1961 a.m. Free Site No. 3

Configuration: Same as previous flight.

Objective: To fly uphill again parallel to slope. This time operator was to go well over the crest to a flag.

Plan View X- - - - 100 Feet Approx. - - - - X

Profile View



Thrust Duration: 13 seconds.

Temperature: 55 degrees F

Relative Humidity: 95 percent

Time (as measured by stopwatch)

Burst: 0.6 sec
First attempt: 2.8 sec
Second attempt: 12.4 sec

Performance: On the first attempt, the operator lifted nicely, but translated too rapidly, and landed a few feet up the slope. On the second, he lifted and translated forward, touched slope, then flew parallel under apparently excellent control up to the flag. The operator described his major problem as pitch control at takeoff.

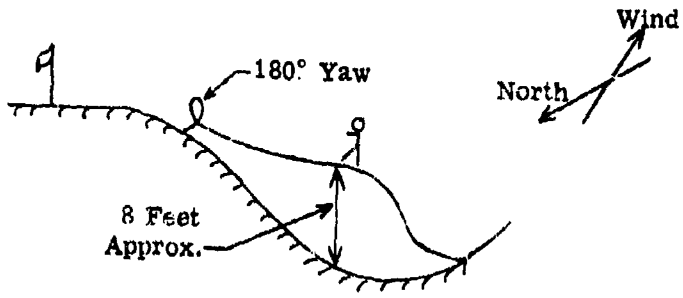
Free-Flight No. 12 (48) May 2, 1961 a.m. Free Site No. 3

Configuration: Same as previous flight.

Objective: To fly up the hill parallel to slope, over the crest to the flag.

Plan View ← – – 100 Feet Approx. –X

Profile View



Thrust Duration: 14 seconds.

Temperature:	55 degrees F
Relative Humidity:	60 percent
Wind:	10 to 20 mph estimated, gusty

Time (as measured by stopwatch)

Burst:	0.5 sec
Flight:	12.5 sec

Performance:

After initial lift-off, the operator ascended almost vertically for a few seconds, then translated toward the slope, while moving off course to the right. Near the slope, he started a slow uncontrolled yaw (180 degrees approximately) and let-down, coming to rest in a seated position facing the starting point. The operator stated that he may have applied inadvertent yaw control when applying pitch.

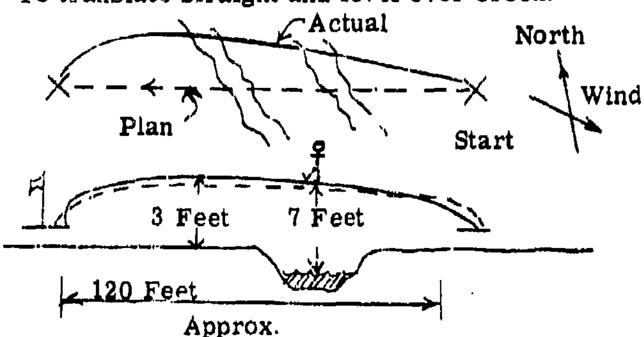
Free-Flight No. 13 (49)   May 2, 1961 a.m.   Free Site No. 4 (Refer to Appendix I)

Configuration: Same as previous flight.

Objective: To translate straight and level over creek.

Plan View

Profile View



Thrust Duration: 16 seconds.

Temperature:	40 degrees F
Relative Humidity:	60 percent
Wind:	15 to 20 mph from NW

Time (as measured by stopwatch)

Burst:	1.0 sec
Flight:	15.2 sec

Performance: Lift off was good, clean and smooth; translation was at steady rate, approximately three feet above the ground. There was no apparent change in altitude as stream banks were crossed. Jet impingement did not cause water spray at this altitude. After crossing stream, operator made a slow turn toward flag, and arrived on target. The operator described the flight as "firm."

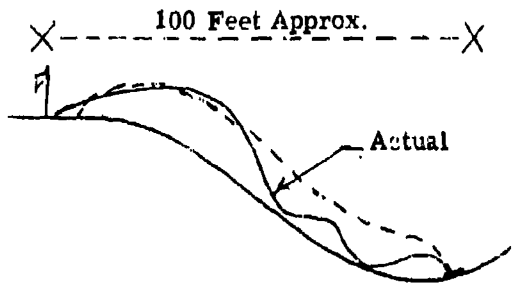
Free-Flight No. 14 (50)   May 3, 1961 a.m.   Free Site No. 3

Configuration: Same as previous flight.

Objective: To fly up hill, over crest to flag.

Plan View

Profile View



Thrust Duration; 15.5 seconds.

Temperature: 40 degrees F

Wind: 20 to 25 mph

Time (as measured by stopwatch)

Burst: 1.0 sec
Flight: 15.0 sec

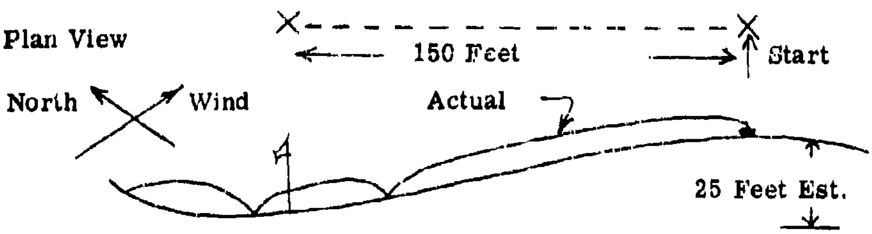
Performance: Initial lift-off was slow. Operator translated forward, touching the slope at two points (as shown in sketch), then flew parallel to slope to flag. The operator stated that he had concentrated on yaw. He had most difficulty in achieving altitude.

Free-Flight No. 15 (51) May 3, 1961 a.m. Free Site No. 5

Configuration: Same as previous flight.

Objective: Perform controlled descent down a hill, parallel to slope.

Plan View



Profile View

Thrust Duration: 16 seconds.

Temperature: 40 degrees F

Wind: 15 to 20 mph

Time (as measured by stopwatch)

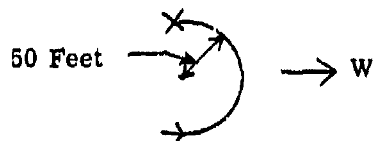
Initial Bursts (2): 1.0 sec
Flight thrust 16.5 sec

Performance: Operator lifted cleanly, then translated parallel to slope, but right of flag. Touched down twice, but continued translation in two short hops as shown. The operator stated that he was most concerned about inadvertently going below 70 percent thrust in let-down.

Free-Flight No. 16 (52) May 5, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To perform left semicircular turn in 50-foot radius:



Thrust Duration: 15.5 seconds.

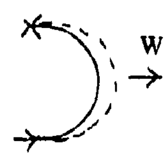
Temperature: 60 degrees F

Relative Humidity: 44 percent

Time (as measured by stopwatch)

Burst: 1.0 sec
Flight: 13.0 sec

Performance: One attempt was made as follows:



Altitude 1 - 2 Feet

Attitude Facing 15 degrees (approx.) off line of travel

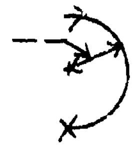
The operator described the turn as difficult. He stated that he cut too sharply.

Free-Flight No. 17 (53) May 5, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To perform right semicircular turn in 50-foot radius:

50 Feet



Thrust Duration: 14 seconds.

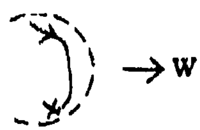
Temperature: 60 degrees F

Relative Humidity: 44 percent

Time (as measured by stopwatch)

Burst: 1.0 sec
Flight: 16.0 sec

Performance: One attempt was made:

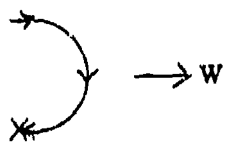


Excessive turning at an excessive translation rate was the major control problem. Propellant signals were unnoticed, i.e., both the light and the auditory signal. The flight operator considered maintaining altitude in the maneuver as his major difficulty.

Free-Flight No. 18 (54) May 8, 1961 a.m. Free Site No. 2

Configuration: Same - except jetavators were loosened slightly.

Objective: To perform right semicircular turn in 50-foot radius.



Thrust Duration: 16.5 seconds.

Temperature: 73 degrees F

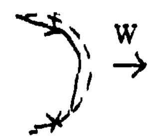
Relative Humidity: 64 percent

Wind: S-SW at 15 mph

Time (as measured by stopwatch)

Burst: 0.5 sec
Flight: 15.5 sec

Performance: One attempt was made as follows:

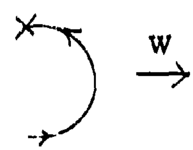


The altitude was approximately three feet. In attitude, he faced off flight path and seemed to side-slip into turns. The operator stated that he set down early, thinking he was out of propellant from the blinking light.

Free-Flight No. 19 (55) May 8, 1961 p.m. Free Site No. 2

Configuration: Same - except "propellant-low" auditory signal removed.

Objective: To perform left semi-circular turn in 50-foot radius.



Thrust Duration: 16.7 seconds

Temperature: 73 degrees F

Relative Humidity: 68 percent

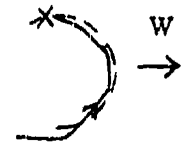
Wind: Southerly at 10-15 mph

Condition: Raining

Time (as measured by stopwatch)

Burst: 1.2 sec
Flight: 16.0 sec

Performance: One attempt was made:

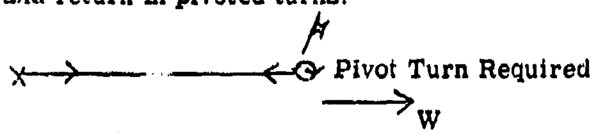


Altitude - approximately 1 foot. The operator seemed again to side-slip into turn. He described his major control problem to be in pitch translation.

Free-Flight No. 20 (56) May 10, 1961 a.m. Free Site No. 2

Configuration: Same - a vibrating signal incorporated in headpiece for "propellant-low" warning.

Objective: To perform straight and steady 50-foot translation, turn and return in pivoted turns.



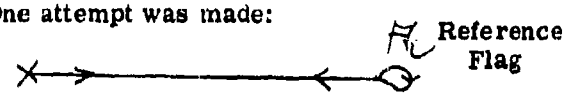
Thrust Duration: 19.5 seconds.

Temperature:	45 degrees F
Relative Humidity:	65 percent
Wind:	N-NW at 10 mph

Time (as measured by stopwatch)

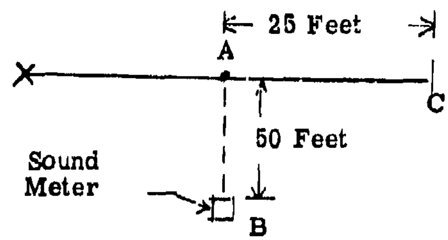
Burst:	1.0 sec
Flight:	20.6 sec

Performance: One attempt was made:



The operator achieved a maximum altitude of approximately 3 -4 feet, seeming to have initial difficulty in clearing the ground. The flight, however, was basically executed as planned. The operator described the vibrating signal as effective, and expressed high-level confidence in the signal.

NOTE: Sound level measurements were obtained during this flight, using a newly-calibrated General Radio Sound Level Meter, Type 1551-B. The meter was positioned midway along the flight path at a distance of 50 feet as follows:

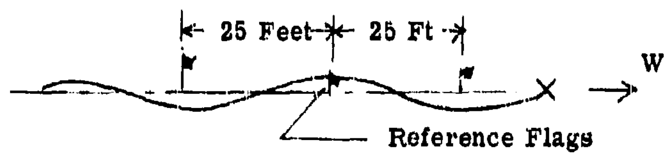


The sound level at point B from A was 124-126 DB; at point B from C (when the turn was executed) it was 128 DB. Previous frequency calculations have indicated a peak at approximately 4000 cps.

Free-Flight No. 21 (57) May 10, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To complete turning maneuvers as follows:



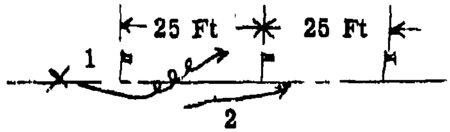
Thrust Duration: 14 seconds.

Temperature:	50 degrees F
Relative Humidity:	65 percent
Wind:	Northwesterly at 3 - 5 mph

Time (as measured by stopwatch)

Burst:	1.0 sec
First Try:	12.0 sec
Second:	4.0 sec

Performance: Two attempts were made as follows:

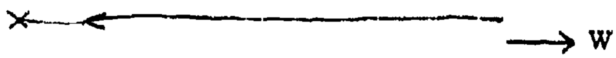


On the first attempt, the operator spun into the turn, lost control and set down. On the second, he side-slipped to the left, tripped and fell to the ground, rolling onto his left shoulder and his head. Maximum altitude was 2 - 3 feet. The flight operator stated that he thought the yaw control hand action was interfered with by right-hand throttle action.

Free-Flight No. 22 (58) May 11, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To accomplish long-range translation and set down.



Thrust Duration: 17.5 seconds.

Temperature: 63 degrees F

Relative Humidity: 38 percent

Wind: E-NE at 14 - 17 mph

Time (as measured by stopwatch)

Burst: 0.5 sec
Flight: 17.0 sec

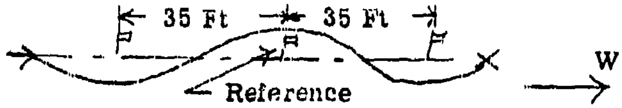
Performance: One attempt was made as follows:

Range covered was 300 feet as measured by tape measure. Maximum altitude was approximately four feet. Maximum velocity was estimated to be approximately 10 - 12 mph. The flight operator observed that precise altitude is difficult to judge, and high velocity can be achieved easily.

Free-Flight No 23 (59) May 12, 1961 a.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To complete turning maneuvers ("slalom") as follows:



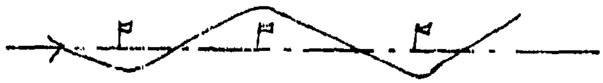
Thrust Duration: 19 seconds.

Temperature:	72 degrees F
Relative Humidity:	64 percent
Wind:	Southwesterly at 5 - 6 mph

Time (as measured by stopwatch)

Burst:	0.5 sec
Flight:	18.5 sec

Performance: One attempt was made as follows:



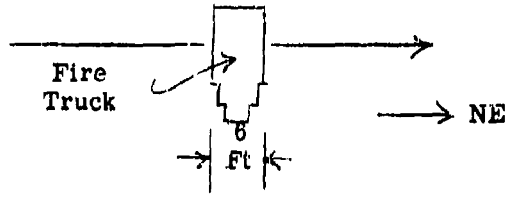
Altitude was approximately 2 - 3 feet. The operator appeared to side-slip into turns, but executed maneuver successfully. The operator stated that he concentrated on yaw control to prevent hand interference.

Free-Flight No. 24 (60) May 12, 1961 p.m. Free Site No. 2

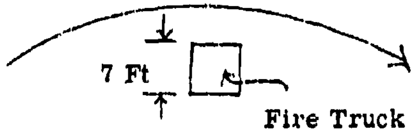
Configuration: Same as previous flight.

Objective: To translate over elevation obstacle as follows:

Plan View



Profile View



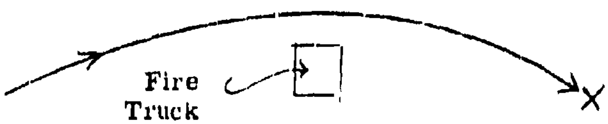
Thrust Duration: 15 seconds.

Temperature:	80 degrees F
Relative Humidity:	64 percent
Wind:	Westerly at 2 - 5 mph

Time (as measured by stopwatch)

Burst:	1.0 sec
Flight:	15.0 sec

Performance: One attempt was made as follows:

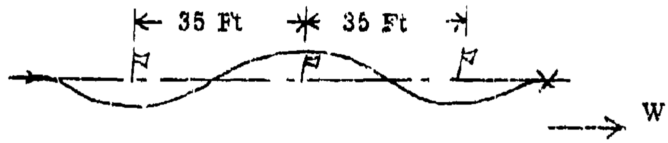


Estimated maximum altitude was 10 to 12 feet. Rate appeared slow and controlled. Total range was approximately 130 feet. In postflight command, the operator expressed high-level confidence in executing maneuver.

Free-Flight No. 25 (61) May 24, 1961 p.m. Free Site No. 2

Configuration: Same as previous flight.

Objective: To practice turning maneuvers ("slalom") as follows:



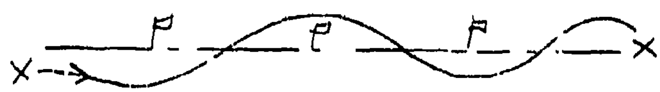
Thrust Duration: 15.5 seconds.

Temperature:	67 degrees F
Relative Humidity:	58 percent
Wind:	SW at 20 - 25 mph

Time (Stopwatch measurement)

Burst:	0.5 sec
Flight:	15.2 sec

Performance: One attempt was made as follows:



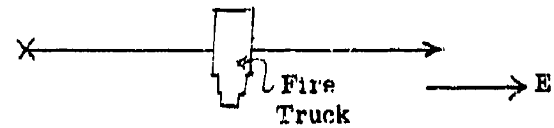
Rate appeared slow and well controlled and operator seemed to bank into turns. The flight operator felt that he had lost no proficiency after a one and one-half week interim period between flights.

Free-Flight No. 26 (62) May 25, 1961 Free Site No. ?

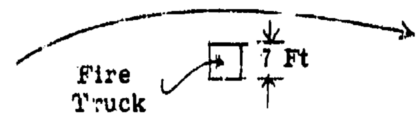
Configuration: Same

Objective: To demonstrate translation over elevation obstacle as follows:

Plan View



Profile View



<u>Thrust Duration:</u> 14 seconds.

<u>Temperature:</u> 70 degrees F

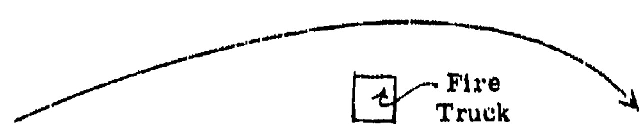
<u>Relative Humidity:</u> 35 percent

<u>Wind:</u> W-SW at 20 -25 mph (sustained gusts up to 35 mph)

Time:(Stopwatch measurements)

Burst:	1.0 sec
Flight:	13.5 sec

<u>Performance:</u> One attempt was made as follows:

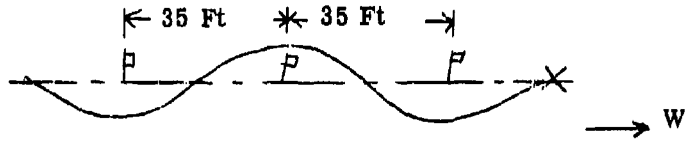


Apex altitude was 10 to 12 feet; range, approximately 125 feet. Some yaw was apparent but operator corrected.

Free-Flight No. 27 (63)   May 25, 1961 (3/4 hours later)   Free Site No. 2

Configuration: Same as previous flight.

Objective: To demonstrate turning ("slalom") maneuvers.



Thrust Duration: 16 seconds

Temperature:

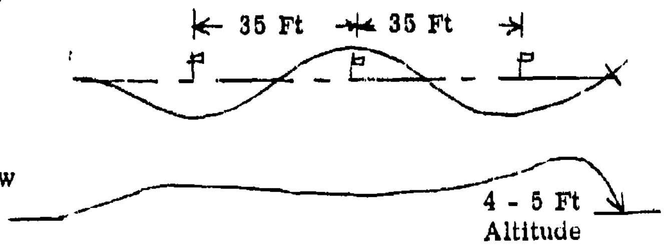
Relative Humidity:

Wind: W-SW at 20-25 mph

Time (Stopwatch measurements)

Burst: 0.5 sec
Flight: 17.5 sec

Performance: One attempt was made as follows:



Rate appeared well controlled, and operator seemed to bank into turns.

Free-Flight No. 28 (64) May 25, 1961 (3/4 hours later) Free Site No. 2

Configuration: Same as previous flight.

Objective: To demonstrate long-range translation.

|← 300 - 400 Feet →

→ E

Thrust Duration: 17 seconds.

Temperature:	70 degrees F
Relative Humidity:	35 percent
Wind:	W-SW at 20-25 mph
Time (Stopwatch measurements)	
Burst:	0.8 sec
Flight:	13.5 sec

Performance: One attempt was made; range traveled was approximately 368 feet; maximum altitude was approximately 5 feet; average velocity was estimated to be approximately 20 mph.

The foregoing descriptions and performance data on the Second Flight Operator in general do not lend themselves to quantitative evaluation, since the test flights were largely exploratory and the tasks qualitative in nature, e.g., to hover, to make short hops, and to translate down range. However, certain indices taken from the test-flight records do provide evidence of proficiency and serve somewhat to establish a trend in the operator's learning curve. Figure 29 presents a plot of the number of times, in the judgment of the tethering man, the operator required assistance, i.e., to prevent his falling, to help him steady himself, etc. Figure 30 is a plot of the number of times the operator attempted to perform a task before he was able to accomplish the plan, i.e., he had to let-down because he was unstable, he was off balance, etc. Figure 31 is a plot of the range off target in translation tasks.

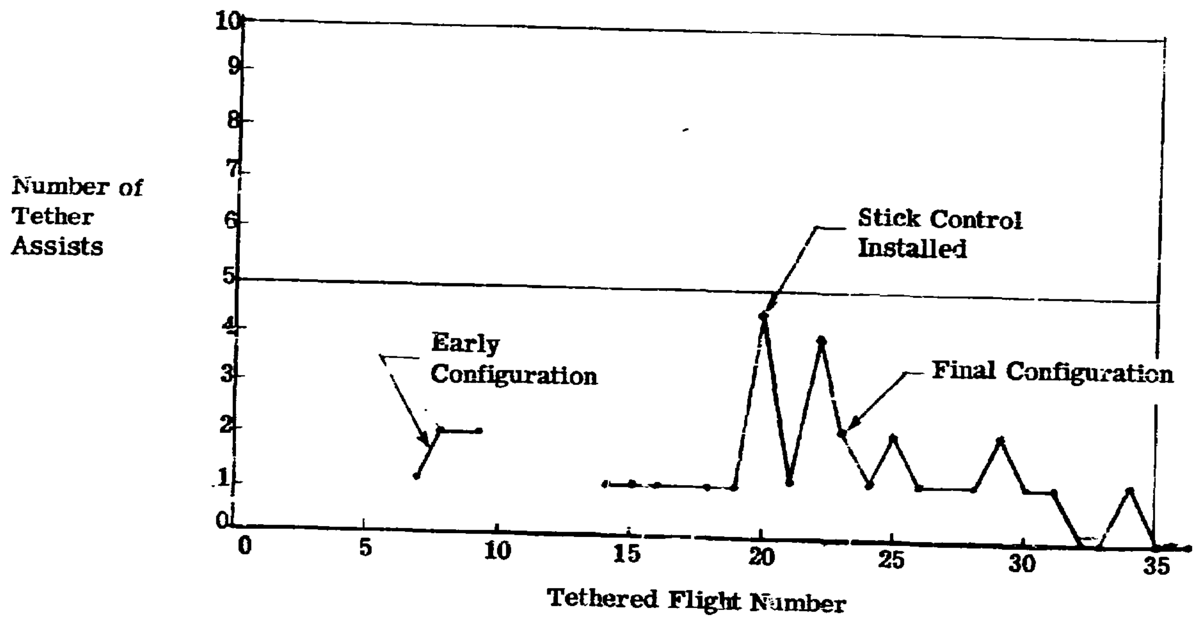


Figure 29. Second Operator's Learning Curve as a Function of Tethering Assists

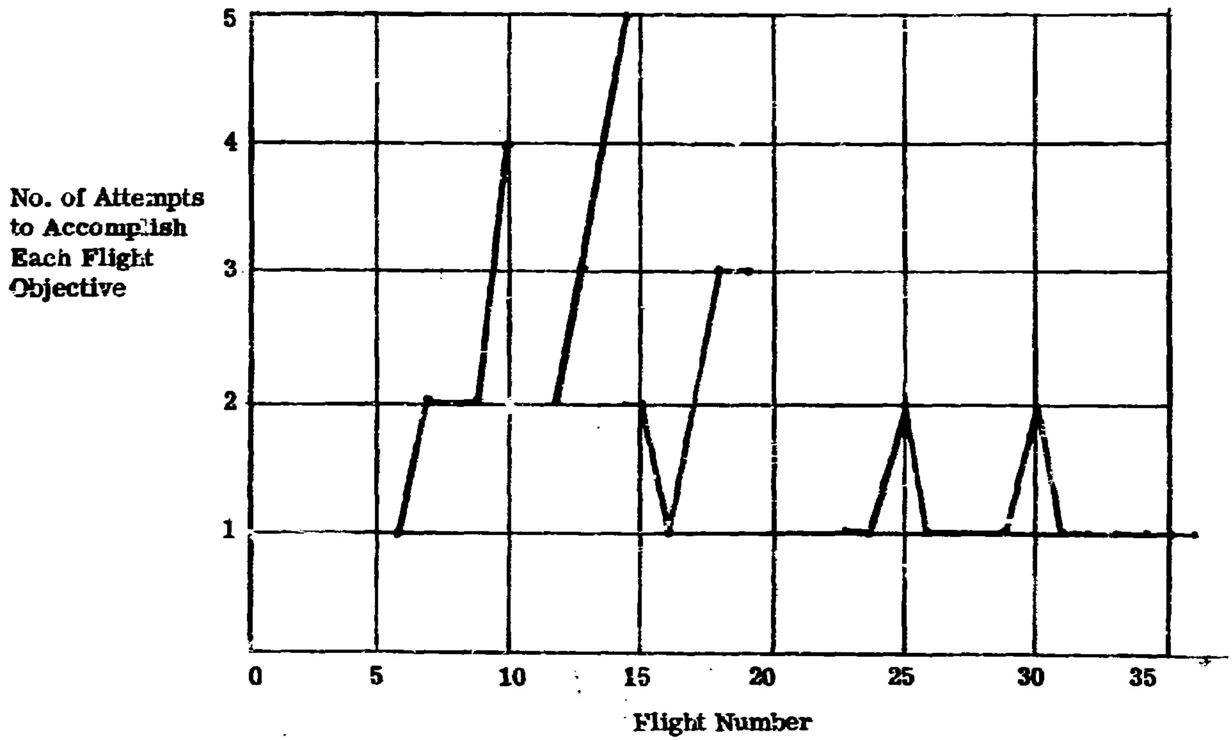


Figure 30. Second Operator Learning as a Function of Number of Tries for Each Task

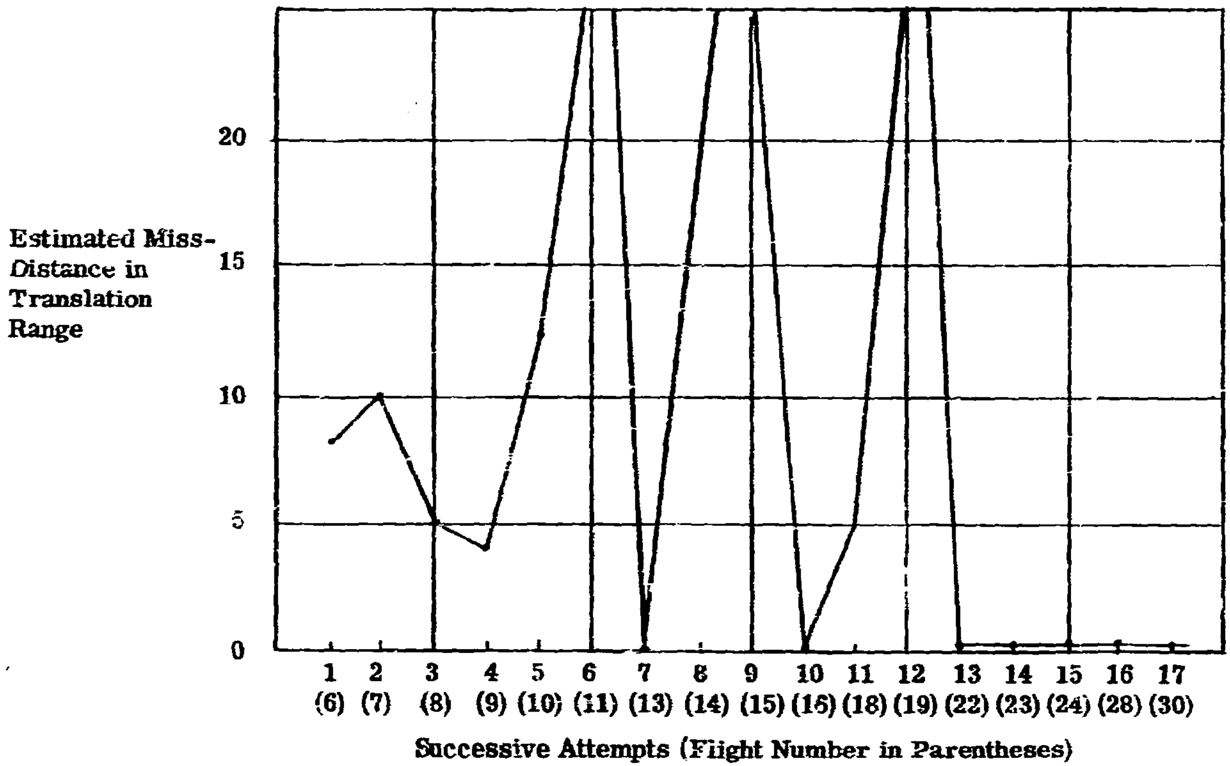


Figure 31. Second Operator Learning as a Function of Miss Distance in Translation

Though the data presented in Figures 29 through 31 are somewhat spotty, they are suggestive of the proficiency of the Second Operator upon which decision to make free flights was based. All plots indicate that on early flights, performance was erratic and inconsistent. Beginning with Flight No. 23, performance of the Second Operator became consistent in accuracy and control. This may have been due, in part, to his increasing skill, but the Operator seems largely to have attributed it to improvements in the rig. He stated at this point: "The present SRLD configuration feels much firmer and less touchy to control. More time is allowed for minor control adjustments. . . "

Subjectively, the Second Flight Operator also evidenced increasing confidence in control. On early flights, for example, he made such statements as follows:

". . . .a stable state can be maintained from the start of a flight; yet, once put into an unbalanced state, no flight to date has shown the ability to re-reach a stable state. . . ."

". . . .started off with a mental fixation of 'riding the bronc' until found in an unsafe or futile state. . . ."

After later flights in the series, he made such comments as follows:

". . . .translations are becoming more and more simple to perform . . . .beginning to get a true 'feel' of SRLD control. . . ."

". . . .the operator felt in full control at all times. . . . "

". . . .flight No. 35 and 36 have given a true picture of the control capabilities and safety of the present man-machine configuration. . . "

Proficiency in free flights has been progressively demonstrated; qualitatively, the operator has accomplished a variety of maneuvers in crossing over a creek and in ascending and descending hills, has performed difficult turning, and has performed long-range translation with skill and and control and, in some cases, under adverse weather conditions.

G. SELECTION AND TRAINING

The present Flight Operator "volunteered" for performing flight tests with the SRLD, and seems to have operated at a consistently high level of motivation, not only from a technical point of view, but from the standpoint of skill acquisition. His biography of motor skills also suggests that they are well above average. He swims, rides a bicycle, water skiis, snow skiis, roller skates, and has owned and operated a motorcycle for over a year. He bowls and plays golf, and plays tennis well. He has also weight-lifted regularly for approximately one year. His current hobby is in operation of power-speed boats. He has ice skated since he was about eight years old, and has played competitively in amateur hockey for over ten years.

Based on the limited data available as criteria for personnel selection and training in operating an SRLD, several generalizations are suggested. These may be of value for selection and training of U.S.Army personnel for possible future operation of prototype models. Criteria for selection and training may be progressively clarified with respect to physical and psychological limitations, special information, skills and adaptions required, as design details of a prototype model are later developed.

1. Selection:

Selection criteria for the flight operator must include:

Height - As pertinent to limitations of a prototype model.

Weight - As pertinent to limitations of a prototype model.

Other Anthropometric Dimensions

As pertinent to limitations of a prototype model, such as waist and hip circumference with respect to hip pack dimensions.

Age

With respect to physiological demands of operations. At present, an age under thirty is suggested.

Operator Anxiety - Apprehension of flight operators may be severe due to the novelty and potential hazards of operations. This, of course, interferes with effective motor behavior. The preliminary data suggests that selection of operators on a "voluntary" basis will largely screen-out those who may be subject to excessive anxiety.

Special Motor Skills - The training-transfer value of such motor skills as involved in skating or skiing seem important.

2. Training:

A training program for prototype models of the SRLD may subsequently be developed from a training functions analysis for both the flight operator and servicing personnel. The following areas of training and equipment, however, are presently suggested for flight operator training.

Basic SRLD Indoctrination - This may include general orientation lectures, the use of charts and motion pictures of SRLD operation, including information on propellant hazards, and witnessing or firing of the SRLD on a special static control stand. As necessary, a handbook and other instructional aids should be provided.

Static and Dynamic Simulator Training - Several simulation activities may be recommended to provide safe and positive training effects. A static simulation, such as employed in REAC control studies, may be considered. Part-task familiarization for adaption to rig "feel" and lifting sensations may be accomplished by simple tethering exercises.

Dynamic simulation training may also be suggested for safe, effective training. A frictionless air bearing platform, such as that currently being used at the Bell Aerosystems Company, may be considered for possible future adaptation to the SRLD simulation training problem. The present device is illustrated in Figure 32. Air jets are applied to raise the plates off a smooth, masonite platform, providing an effectively frictionless stance for the operator. His ability to control his motion by means of reaction jets can be easily scored for proficiency. This device could be adapted, and may be suggested for future SRLD simulation training.

Tethered Flight Training - Requirements for a tethered flight training phase must be established preparatory to free flight. If personnel are carefully selected for specially adaptable skills, and provided with adequate simulation training and indoctrination, it is presently estimated that approximately 15 tethered flights may be sufficient to provide proficiency for free flight. Tethering-control personnel may be considered for interchanging functions

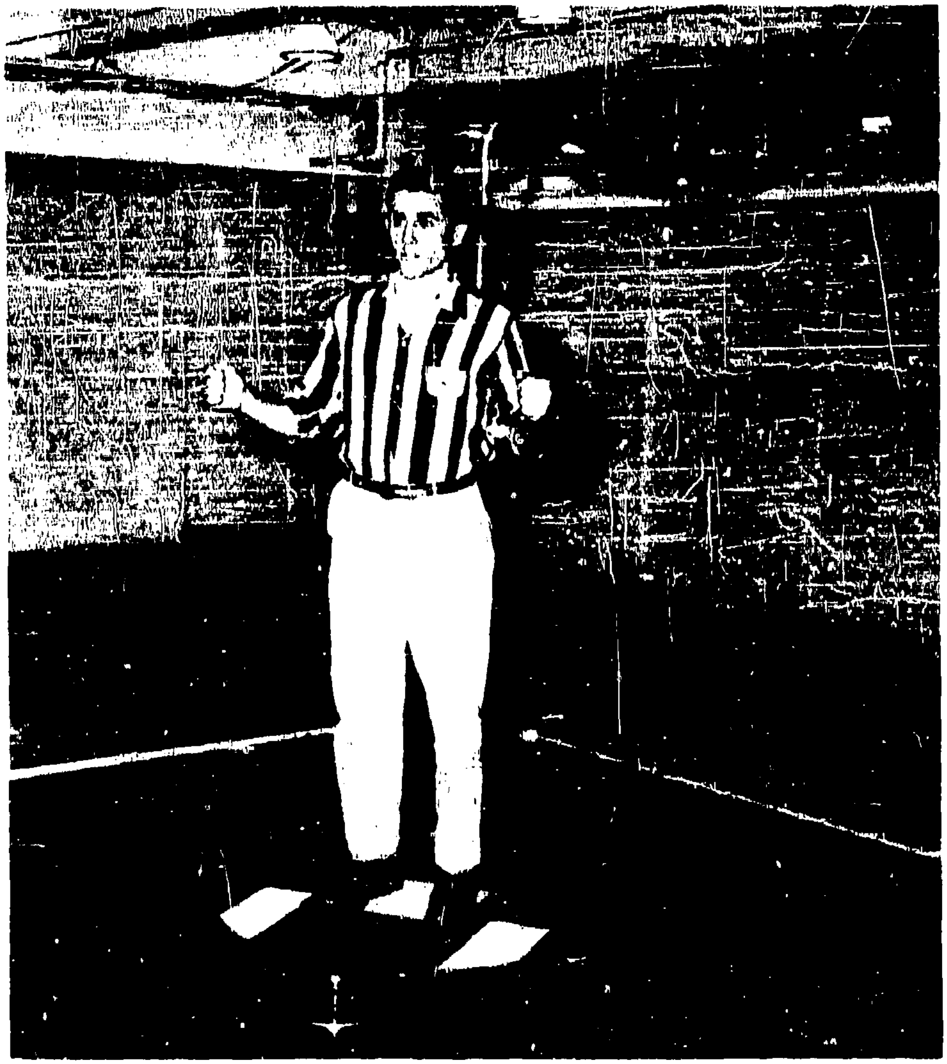


Figure 32. Air Bearing Platform

with the flight operator. Their training would then be essentially that of the flight operator, supplemented by special instruction in tethering control.

Free-Flight Training - A simple-to-complex free-flight program may be suggested, similar to that carried out in the present test program. A level of proficiency should also be established as "combat-ready" criteria for use of the SRLD in the field.

It is also suggested as most expedient that servicing personnel should be largely trained in an on-the-job situation.

V. RELIABILITY

The flight reliability of the SRLD can be expressed:

$$R_{srld} = R_o \times R_s$$

where

R_o = Reliability of the operator

R_s = Reliability of system hardware

This rigorous flight reliability interpretation takes into account those flights that will fail due to operator error, although the system hardware has demonstrated an observed reliability of 100% with a corresponding high degree of confidence. From a logistics point of view, this rigorous reliability computation will be necessary for determing the number of flights to be scheduled for a desired number of successes. However, the reliability of the operator (R_o) can only be determined by sufficient operational data and cannot be established in this R&D phase of the program. Therefore the only reliability computed during Phase II was that which was demonstrated by the SRLD hardware.

During Phase II testing a total of 89 system tests were conducted. These tests consisted of 9 various thrust level and lift tests, 56 tethored flight tests, and 24 free flight tests. No failures were observed during these tests,resulting in an observed reliability of 100% and a demonstrated reliability, at 90% confidence, of 97.5% as indicated in Figure 33.

The reliability demonstrated indicates that if this system were in production we could expect 39 successful flights before a malfunction.

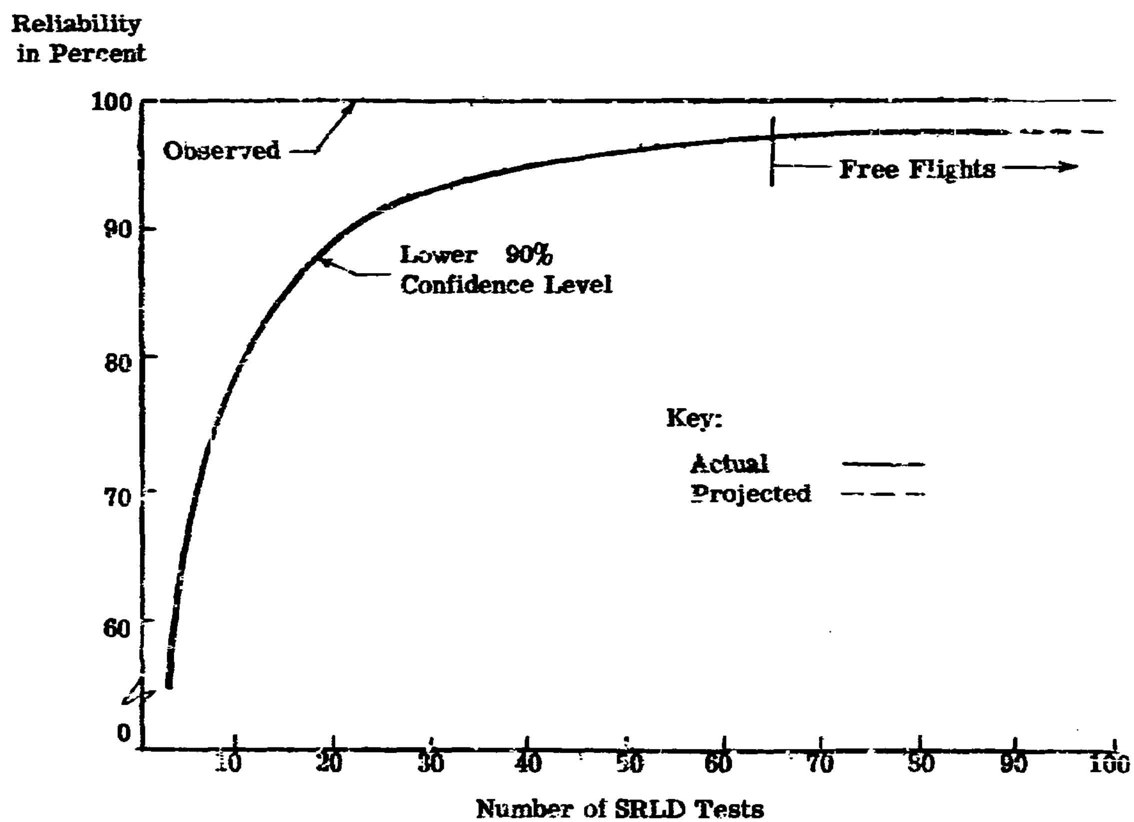


Figure 33. Observed Reliability of SRLD with Lower 90% Confidence

VI. OPERATIONS ANAYLSIS

A. SURVEY METHODS

The Systems Support Group of the Bell Aerosystems Company undertook an operational study of the SRLD during the Phase II program. Several U. S. Army field agencies were contacted by phone and mail to obtain information on how such a device as the SRLD might be employed in Army field problems. A general description of the SRLD feasibility model, together with illustrations, was provided with each mailed questionnaire.

The basic operational question addressed to each agency was how such a device as the SRLD could be applied to Army field problems. In this analysis, we asked to have the thinking of experienced field personnel about how they felt such a device could be employed in practical situations.

The following questions were suggested for consideration:

(1) Do you think that a device such as the SRLD has practical feasibility for use in the field?

(2) Please describe specific operations for which you envision the possible use of such a device.

(3) What do you think the minimum desirable performance characteristics of such a device should be to meet these operational requirements?

(4) What do you consider to be tolerable (i.e., in terms of time required, difficulty, etc) handling and servicing requirements for the operations you have described?

(5) From what supply source would you expect to be provided with this type device, i.e., Battalion S-4, Engineer Supply, etc?

(6) What type of units do you think would have the most use for a device of this type?

B. AGENCIES CONTACTED

The following agencies of the U. S. Army were contacted by phone and through the mail:

The Psychophysiological Group,
The Equipment Branch,
The Technical Clothing and Footwear Sections of the U. S. Army Quartermaster Research and Development Center
Natick, Massachusetts

Human Resources Research Office
U. S. Army Infantry Human Research Unit
Ft. Benning, Georgia

Training Methods Division
Human Resources Research Office
George Washington University
Washington, D. C.

U. S. Army Aviation
Human Resources Research Office
Ft. Rucker, Alabama

U. S. Army Office of the Chief of Research and Development
Washington, D. C.

Documents and Combat Development Division
Future Organization and Combat Branch
Office of the Deputy Chief of Staff for Military Operations
Washington, D. C.

Combat Material Division
Combat Arms Branch
Office of the Deputy Chief of Staff for Research and Development
Washington, D. C.

Combat Development Office
Infantry School
Ft. Benning, Georgia

Combat Arms Division
Tactical Branch
Office of the Deputy Chief of Staff for Combat Development
Ft. Monroe, Virginia

Military Advisor, Tactics Division - ORO
Bethesda, Maryland

C. UNOFFICIAL THINKING OF U. S. ARMY FIELD AGENCIES

Replies to the mailed questionnaire were received from the following agencies:

1. U. S. Army Quartermaster Command at Natick, Mass.
2. U. S. Army Infantry Research Unit at Ft. Benning, Ga.
3. U. S. Army Infantry School at Ft. Benning, Ga.
4. U. S. Army Aviation Human Research Unit at Ft. Rucker, Ala.

The U. S. Army Quartermaster Command at Natick, Mass. provided the following comments:

(1) The present device is very heavy. It is almost certain to be very cumbersome in use unless weight is reduced.

(2) In its present form it develops 130 db, a very noisy device. It is sure to advertise its presence over a wide radius. As it becomes known in combat for its tactical potential, it is sure to become a favored target, making its users very unpopular. This may adversely affect its acceptance by combat troops. Coupled with the fact that the user becomes a low-flying slow-speed aircraft with no camouflage as he rises above the terrain, the question arises as to just how effective this item can become.

(3) Special attention will probably have to be given the harness system by which the device is attached to the user. If it is considered that a rocket system is characterized by very high thrust, it should be kept in mind that such power delivered suddenly may do serious injury to the man who goes along with it. If the harness system does not distribute the load application over the human structure in a manner permitting it to be absorbed, pressure points will be very likely to cause serious injuries. It may be that harness design will not be sufficient. It may be necessary to incorporate a controllable valving system to allow thrust to be applied gradually. However, this loses thrust, requiring more fuel, hence, more weight on the man. Could be a vicious circle?

(4) Safety features will require comprehensive study. Some of the more important ones:

(a) Rocket backwash is apt to be hazardous to both the user and support personnel. Without knowing specific details, it would still seem that hot steam blasting back strongly enough to impart movement would be of some risk to assistants who are left behind in line with the man's travel path. Support personnel will probably have to be warned of this. Also, since the man's legs extend back of the hardware, he is apt to be vulnerable to injury. In straight motion in still air, it is probably safe enough. But still air is a rarity. What happens in turbulent air, where the backwash is apt to be blown around?

(b) Fuel burnout leaves the man "up in the air". Three types of fuel failure immediately come to mind:

(1) Sputter - this intermittent application and removal of thrust could cause considerable stress to be placed upon the man. It would also raise great problems for control of flight stability.

(2) Complete failure - this would leave the man at a fatal height without even the partial protection provided in disabled aircraft through auto-rotation, dead-stick glide, and impact energy absorption provided by the cockpit of conventional vehicles.

(3) One single power interruption - this would probably cause the man to go out of control when power fails; then, when his power goes on again, intensifying the problem, unless he is capable of reacting correctly to prevent his being "driven into the ground".

(c) Steering and guidance will have to be surveyed carefully. Considering that the man is effectively airborne, the problem then becomes one of manipulating himself as a free-moving object at considerable velocity. Very likely the task is extremely difficult, requiring superior reaction time, discrimination reaction time, and judgment and decision making, superior judgment of spatial relations and depth discrimination, and good athletic coordination. Such a combination of factors is not a rarity, but it is unusual.

Therefore, this device will most likely require considerable training of preselected user personnel. It is not apt to be a device which can be issued carte blanche to troops as rifles are.

(d) Recovery from loss of control - this will have to be studied. Considering a total flight time of 30 seconds, a few seconds of which are used in becoming airborne, what chance will a man have to recover from loss of control, such as tumbling, veering, spinning, etc.?

All in all, although this device has intriguing possibilities which should be explored thoroughly, I think it should be recognized that this equipment will be no snap to operate, will require training of talented people, and will have built-in hazards inherent as part of the concept. With these limitations in mind, it would still constitute a powerful military tool.

Items in reply from the U. S. Army Infantry Research Unit at Ft. Benning were noted as follows:

(1) The practical feasibility of such a device is completely dependent upon characteristics.

(2) If otherwise dependable, the most valuable tactical use would be in crossing horizontal obstacles such as streams, ravines, or gaps such as those blown in cliff roads, etc. Dubious over use as an observation post or in scaling vertical obstacles until more information is available relative to return possibilities. Device might also be of considerable value as a discardable aid in amphibious operations in the passage from landing craft to beach, particularly under rough surf conditions.

(3) Minimum characteristics should be:

(a) 25-30 pounds maximum weight.

(b) Acceptable guidance.

(c) Acceptable return capability.

(d) Field conditions demand GI operation simplicity, dependability and ruggedness under all climatic conditions.

(4) Time required in support and service of such a device would be less important than weight, simplicity, ruggedness and other such characteristics.

(5) Engineer supply would be the major supply source.

(6) Assault, Light Reconnaissance, and Combat Engineer Units would have most use for such a device.

The U. S. Army Infantry School at Ft. Benning, returned the following comments:

The U. S. Army Infantry School is interested in any means of improving the mobility of the foot soldier and therefore, reviewed your description of a small rocket lift device with interest.

The Infantry visualizes using a lift device for negotiating obstacles such as precipitous terrain, ravines, rivers, minefields and contaminated areas. This device would facilitate movement of the individual soldier in areas where mechanized vehicles could not operate, and in special operations limited to foot movement only, such as raids, patrols, ranger and amphibious operations. Operations by rangers, special forces, and combat engineers involving negotiation of obstacles which require tedious movement and the use of other special equipment such as grapnels and pikes could be sped up, thereby decreasing exposure time and enhancing the successful accomplishment of the mission.

The device should be provided with a simple manual control system which will provide positive stabilization and control of steering and speed during operation. A minimum continuous operating time of thirty seconds is required. The device must be capable of being refueled in the field, by the operator, without the use of bulky auxiliary equipment.

Integration of small rocket lift devices into Infantry units should not introduce any new maintenance problems. It must be a simple device which can be maintained by the average soldier by such simple operations as keeping critical points free of dirt accumulation and checking a minimum number of points visually to determine whether the device is serviceable and safe to use.

We feel this device will be issued in limited numbers, to company sized units for use by selected individuals when required. Additional devices would be obtained through normal unit supply channels as a Class IV Item (items requested as needed and in the quantities needed) when the situation requires augmentation. Recharging would probably be done by special support echelon units in rear areas; therefore, this device must be capable of exchanging empty fuel cylinders for full fuel cylinders.

The U. S. Army Aviation Human Research Unit at Ft. Rucker, Ala., presented the following comments as a synthesis of their unofficial thinking about the device:

(1) The consensus seemed to be that the SRLD offered a number of practical possibilities. The generality of use of such a device would be a function of training and servicing requirements and operating limitations.

(2) The potential operations in which the SRLD might prove useful can be categorized as follows:

(a) Transport of personnel over minor obstacles.

(b) Transport of personnel with specific equipment (signal, engineer) over obstacles.

(c) Elevation of personnel for purposes of observation.

(d) Uses in aviation.

Under (a), such things as lift of an Infantry Battle Group or Company-size unit over obstacles were mentioned. This would be of great value in a surprise assault. Another area of use might be Infantry night patrols.

Engineer units could utilize the SRLD to advantage in bridge-building operations for transport of light equipment (b). Signal corps uses would include wire-laying and lift of radio equipment onto high terrain features for maximum utility.

Uses mentioned under (c) were lifting Artillery personnel to high terrain features for observation purposes, use by tank platoon commanders for short reconnaissance, and in inspection of atomic blast areas by Chemical Corps personnel.

Not too many specific aviation uses (d) were mentioned. It is possible that a device of this sort might be developed to replace low-altitude ejection systems. This is a pertinent problem for Army Aviation with its great stress on low-level, nap-of-the-earth flying. Army aircraft frequently operate at altitudes where the ordinary parachute is useless. In higher-performance aircraft, such as the L-19 and all the helicopters, this capability is lacking. Under certain circumstances, it might be more advisable to "bail-out" with an SRLD than to autorotate a helicopter or make a forced landing in a fixed-wing aircraft.

The SRLD might also be of some use in airlift and landing of special troops (medics, observers, etc.) in remote or confined areas. For example, if a helicopter cannot land in a confined area and cannot hover with sufficient stability to permit dropping personnel by ladder or other means, then the SRLD might be the answer.

The most intriguing use that occurred to several of us here would be to wed your device with the flex-wing glider concept of the Ryan people. It would seem that using the SRLD for the motive power, with the flex-wing supplying most of the lift, would give a tremendous mobility and maneuverability to the individual soldier for special operations. This might greatly simplify the coordination of thrust and lifting moments in the use of the SRLD. Whether such a marriage is feasible or not, I do not know. I would be interested in what your engineers think. We, here, were greatly impressed by the Ryan presentation on their flex-wing.

(3) The performance characteristics necessary would vary with use, but here is an over-all summary of the comments.

(a) Thirty minutes fuel.

(b) Forward speed capability of 15 mph.

(c) Figuring average equipped soldier at 200 pounds, the SRLD should be able to lift soldier plus 50-pound load (total 250 pounds).

(d) Minimal training required to learn to "fly" the device.

(e) No special clothing required.

(f) Night capability.

(4) A maximum of one hour for equipment check prior to use. For Infantry operations, no servicing should be required. For use by Engineer and Signal Units, servicing should be minimal with two-day supply. Service equipment should be easily transportable and require minimal training for operation.

(5) For use by Signal, Engineer, and Artillery battalions, the supply should be organic to the battalion. Use by the Infantry would be for special and infrequent operations. Therefore, supply could be at the Army supply point. No servicing would be required of the user. After the operation, the SRLD units could be policed up and sent back to the Army supply point for servicing.

(6) As previously indicated, Signal, Engineer, and Artillery might have fairly regular use for the SRLD, while the Infantry requirement would be periodic.

(7) GENERAL. Answers to the following questions would make it easier to assess the practicality of the SRLD for Army use:

(a) How much training is necessary for operating the SRLD?

(b) What is the size and weight of servicing equipment?

(c) How much personal equipment can the operator carry?

(d) How many services will servicing equipment provide before recharge or maintenance?

(e) What is the estimated cost of unit and allied equipment under mass production?

(f) How much of a safety problem is involved in handling and servicing?

(g) What additional support items are required for operator and service personnel such as helmets, special clothing, etc.?

The Operations Analysis Branch of the Combat Operations Research Group, at Ft. Monroe, Virginia, volunteered the following informal comments:

> "Our thinking on the problem. . .would indicate that a device to extend the individual's physical capabilities would be most useful. The capability of "flying" is, in our opinion, not required. The practical uses for such a device would include jumping up on a roof or down a steep cliff or across a small stream. The characteristics of the device which, in our estimation, are required, might be described as those of an anti-gravity device suitable for intermittent operation for one battlefield day."

A reply in the current study, was not received from the Office of the Director of Research and Development, Combat Arms Branch in Washington. However, it was noted from discussion with members of this staff several years ago that in their opinion such a device as the SRLD would be extremely valuable. Use, it was noted, would be made by specialized task-force personnel to get the first rope across the river or up a cliff. Only special personnel would be assigned to operate the SRLD.

D. SUMMARY OF DATA

Table 6 presents a summary of comments made by U. S. Army agencies on possible SRLD field applications.

A rank order of requirements, in terms of frequency of comments made independently by each agency, is presented in Table 7.

TABLE 6

SUMMARY OF COMMENTS BY U. S. ARMY FIELD AGENCIES COVERING POSSIBLE OPERATIONAL EMPLOYMENT OF AN SRLD

Descriptive Requirement	Total No. of Times This Was Stated As A Requirement
1. Use in translation problems, e.g., across rivers, over horizontal obstacles-streams, ravines, gaps blown in cliff roads, landing-craft-to-beach, crossing minefields..	11
2. Use in altitude problems, e.g., for observation, lift equipment onto high terrain features, negotiating precipitous terrain, going over contaminated areas, obviating use of grapnels, jumping to roof top.	8
3. Discardable item, e.g., in assault.	1
4. Light gross weight	3
5. Specialized use only	6
6. Simplicity of operation	3
7. Paraglider application	1
8. Fuel duration -- 30 minutes	1
9. Fuel duration -- 30 seconds	1
10. Lifting capability 250 pounds	1
11. Minimum training	1

TABLE 6 (CONT)

Descriptive Requirement	Total No. of Times This Was Stated As A Requirement
12. Servicing simplicity	4
13. Likely using units:	
Assault	3
Light Reconnaissance	1
Combat Engineers	1
Infantry	3
Artillery	1
Armor	1
Aviation	1
Signal Corps	1
Chemical Corps	1
Medical	1

TABLE 7

SRLD OPERATIONS REQUIREMENTS

Rank Order	Requirement
1	Translation
2	Ascent-descent
3	Limited for use by select and skilled personnel only
4	Servicing simplicity
5.5	Light gross weight (25-30 pounds)
5.5	Simplicity of operation for general use
7	Miscellaneous

These operational data, based upon unofficial opinions and informal judgments by U. S. Army personnel, are of course limited and inconclusive. However, in generalizing on the basis of trends suggested in the data, what apparently is basically needed is a device that will permit a single individual to cross horizontally over obstacles. The ability to climb may be secondary. The operators may be specially selected and trained. The operating device must be lightweight, e.g., less than 30 pounds gross weight, and easily serviced and maintained in the field.

U. S. Army reservist personnel within the Bell Aerosystems Company were also asked to provide conceptual data on an operational SRLD. In their thinking, too, the device seemed to have more potential application for problems in horizontal travel than in vertical. Under horizontal applications they listed such things as (1) crossing rivers and ravines to carry lead lines in building of foot bridges, etc., (2) raids and patrols over barbed wire obstacles, (3) amphibious operations from landing craft to beach, (4) crossing chemical-biological-bacteriological-radiological (CBR) contaminated areas. They also suggested the need for a radio-controllable device for lifting equipment and supplies.

Use in possible vertical applications they considered to be limited to such problems as cliff scaling. For observation-type applications they considered a special-type design low-altitude tethered balloon platform to be more feasible than an SRLD.

They too, considered that use of an SRLD would be largely restricted to specially selected and trained personnel, and called for only in occasional field problems. Conditions of operation they considered important to tactical field use were as follows:

(1) Control of heat and noise

(2) Providing safety and confidence in operation, including provisions for quick disconnection.

Desirable operational characteristics were listed as follows:

(1) Readily replaceable fuel supply, easily transferred in the field.

(2) Efficient system of re-servicing cartridges or cylinders at the service depot.

(3) One-half minute of full thrust/one minute of half thrust.

(4) Reliable flight stability and control.

(5) Maximum gross weight not to exceed 50 pounds.

(6) Ease and comfort in operation.

(7) Adaptable for remote control operations.

(8) Rugged and durable construction.

VII. REFERENCES

1. Aerojet - General Corporation "Feasibility Study of A Small - Rocket Lift Device" - Final Report No. 1751 - Feb. 1960

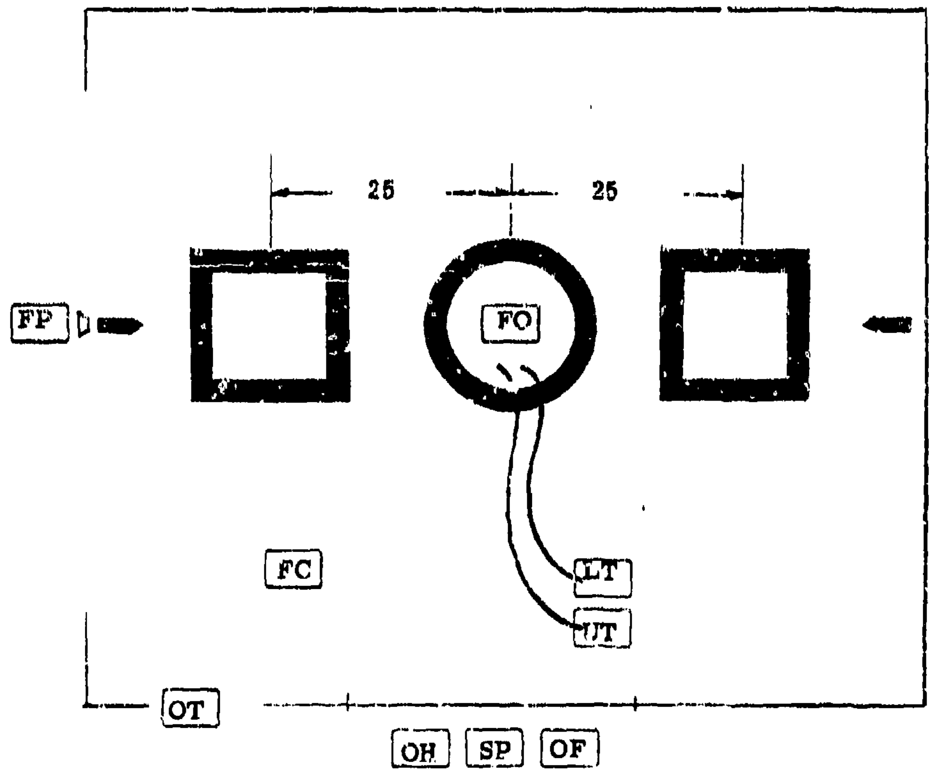
2. Bell Aerosystems Company, "Phase I Technical Report No. 61-45 dated April 1961.

APPENDIX I

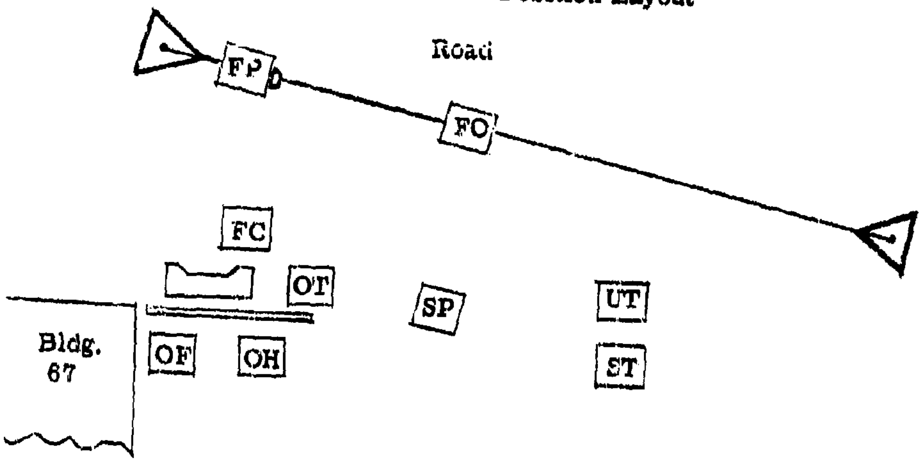
SITES AND PROCEDURES IN SRLD FLIGHT TESTING

A. TETHERED FLIGHT TEST SITES AND PROCEDURES.

Tethered Site No. 1 - Bldg. 67 - Plan Position Layout



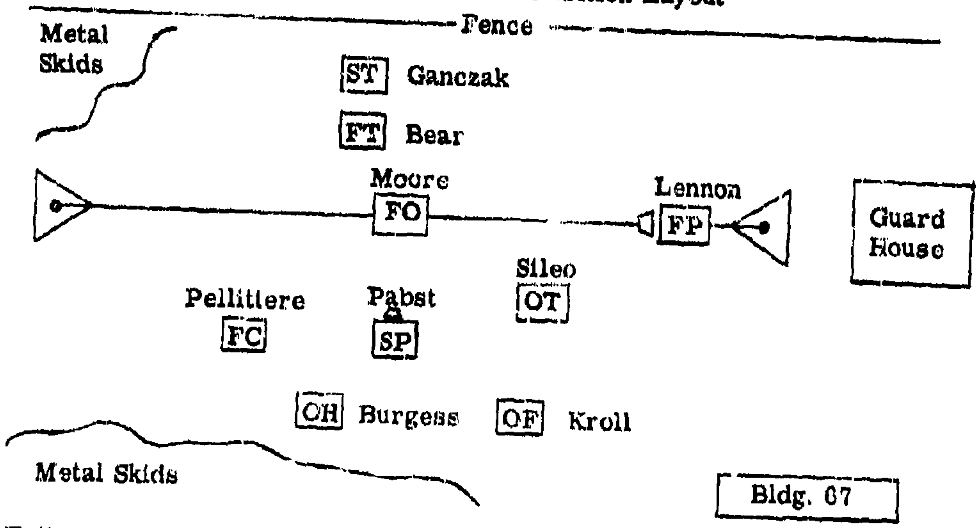
Test Area Plan Position Layout



Tethered Site No. 2 - Outside Building 67

Check List (Rev. C)

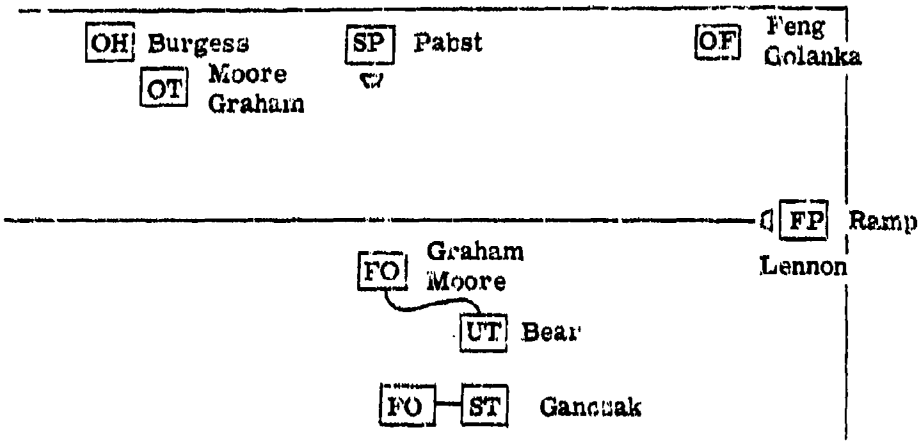
Ramp Test Area Plan Position Layout



Tethered Site No. 3

Check List (Rev. D)

SRLD - Hangar Test Area Position Layout



Tethered Site No. 4 | Check List (Rev. G)

Position Callout

FP First Photographer - Tom Lennon

SP Second Photographer - Glen Pabst

OT Observing Test Engineer - W. Moore
H. Graham

OF Observing Control Engineer - T. Feng
R. Golanka

OH Observing Human Engineer -
J. Burgess

FO Flt. Operator - W. Moore
H. Graham

UT Upper Tether - "Bear"
Kreutinger

ST Second Tether -
E. Ganczak

FC Flt. Test Coordinator -
E. Ganczak

TS Tank Service Man - Topanak (not shown)

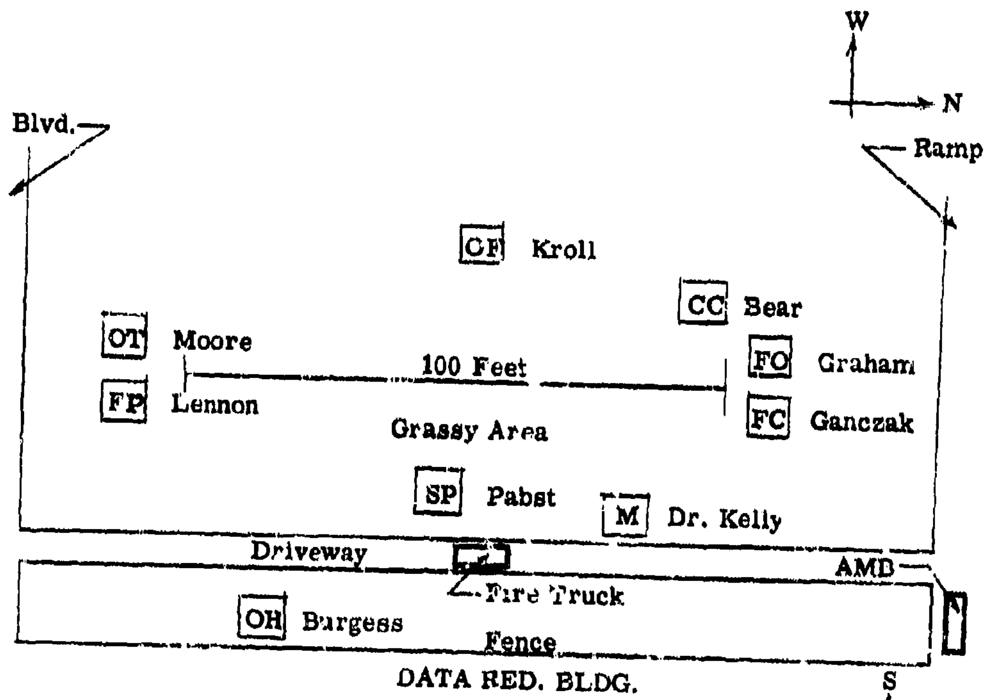
Ganczak

1. Confirm that floor plugs are cut, and power is available for camera lighting.
2. Confirm SRLD test configuration, tanks are loaded and checked.

	3. Check that all exposed personnel have ear protectors and goggles.
	4. Check that fireman is at station.
Graham	5. Re-confirm configuration and flight task.
Ganczak	6. Check that flight-test crew are in position as above.
Graham & Ganczak	7. Confirm nitrogen tank is pressurized and checked. Record pressure.
Graham	8. Don SRLD.
Graham, Bear, Ganczak	9. Move into flight position and remove cart.
Bear & Ganczak	10. Confirm that top tethering is connected, secure and free, and area is clear.
Graham & Bear	11. Confirm ready for take-off.
Graham	12. Confirm P&V valve in press position.
Graham	13. Confirm pin is removed from throttle handle.
Graham & Ganczak	14. Open shut-off valve slowly. Check and call out H_2O_2 tank pressure. Record.
Lennon & Pabst	15. Check that cameras are on.
Graham	16. Signal for camera synchronization.
Graham	17. Take-off and complete maneuvers according to flight plan.
Feng	18. Start timer and record time of run.
Graham & Ganczak	19. After landing, vent tanks, close N_2 shut-off valve, call out and record source pressure remaining.
Lennon & Pabst	20. Confirm that cameras are off.
Bear	21. Disconnect tether connections to suit.
Graham & Bear	22. Position and doff SRLD for loading.

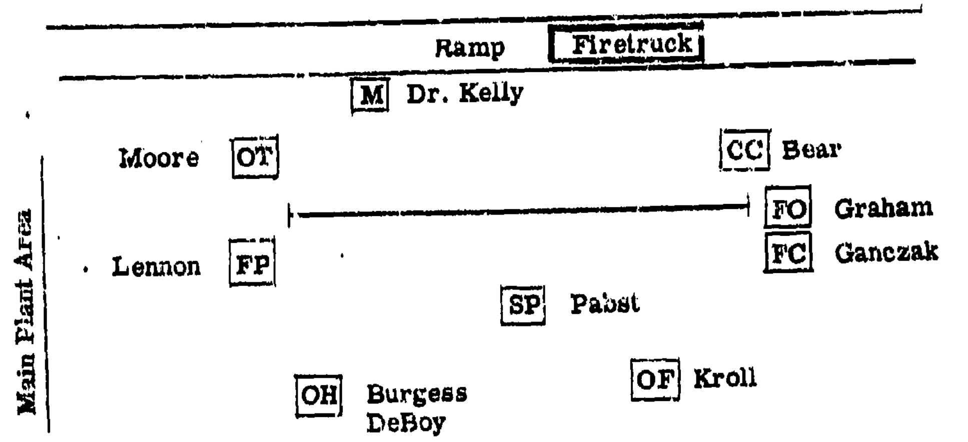
Ganczak & Burgess	23.	Call entire crew together for de-briefing on previous flight.
All Crew	24.	Complete Flight Rating Chart and remarks.
Burgess	25.	Interview all observers; collect, mark and collate verbal data.
Ganczak & Burgess	26.	Plan next run and brief crew.

B. <u>FREE-FLIGHT TEST SITES AND PROCEDURES</u>

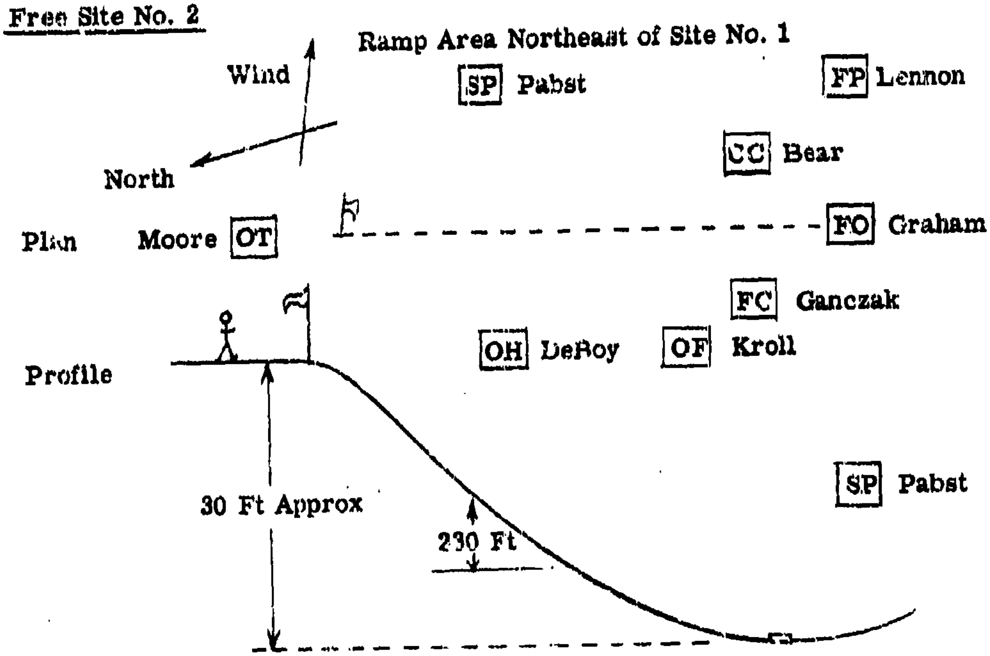


Free Site No. 1

Outside Area West of Hangar, Position Layout

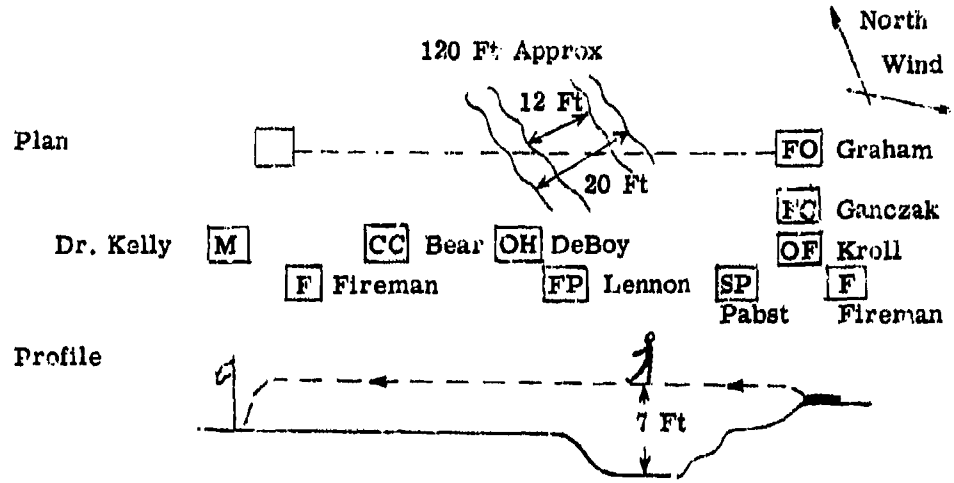


Free Site No. 2



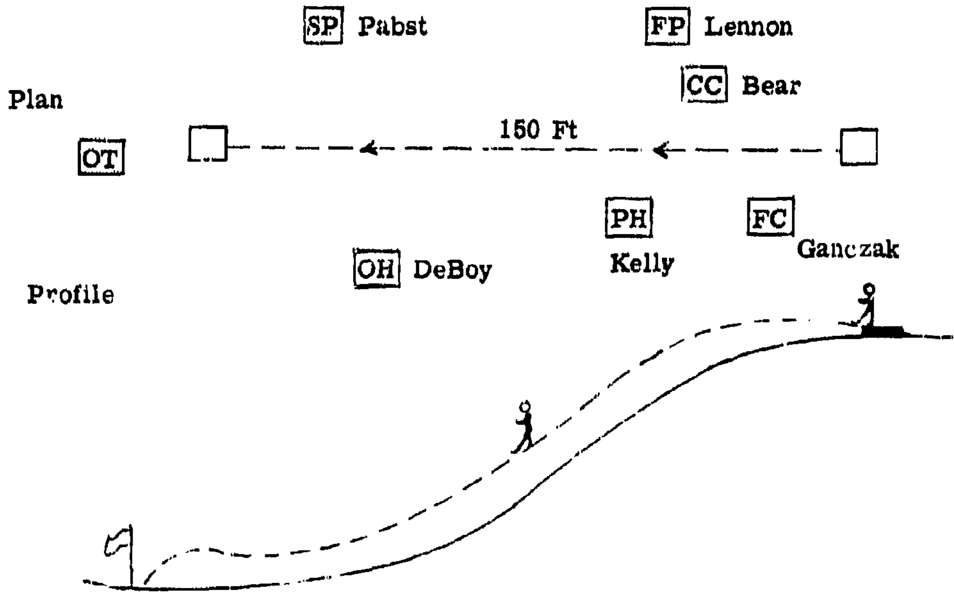
Free Site No. 3

Niagara Frontier Golf Course, Fairway - Upgrade



Free Site No. 4

Niagara Frontier Golf Course - Water Hazard



Free Site No. 5

Niagara Frontier Golf Course - Fairway - Downgrade

Position Callout:

FP	First Photograph - Tom Lennon	FO	Flt. Operator - H. Graham
SP	Second Photograph - Glen Pabst	CC	Crew Chief - E. Kreutinger
OT	Observing Test Engineer - W. Moore	FC	Flt. Test Coordinator - E. Ganczak
OF	Observing Control Engineer - J. Kroll	M	Medical - Dr. Kelly
OH	Observing Human Engineer - J. Burgess, M. DeBoy	F	Firemen

Ganczak	1.	Check and confirm SRLD test configuration, tanks are loaded and checked.
Ganczak	2.	Check that all exposed personnel have ear protectors and goggles.
Ganczak	3.	Check that firemen are at stations.
Graham	4.	Re-confirm configuration and flight task.
Ganczak	5.	Check that flight-test crew and observers are in position as above.
Graham & Ganczak	6.	Confirm nitrogen tank is pressurized and checked. Record pressure.
Graham	7.	Don SRLD.
Graham, Ernie, Ganczak	8.	Move into flight position and remove cart to end of driveway.
Graham & Bear	9.	Confirm ready for take-off.
Graham	10.	Confirm P&V valve in press position.
Graham & Ganczak	11.	Open shut-off valve slowly. Check and call out H_2O_2 tank pressure. Record.
Graham	12.	Confirm pin is removed from throttle handle.
Lennon & Pabst	13.	Check that cameras are on.

Ganczak	14.	Signal for camera synchronization.
Graham	15.	Take-off and complete maneuvers according to flight plan.
Moore & Burgess	16.	Start timer and record time of run.
Graham & Ganczak	17.	After landing, vent tanks, close N_2 shut-off valve, call out and record source pressure remaining.
Lennon & Pabst	18.	Confirm that cameras are off.
Graham & Bear	19.	Position and doff SRLD for loading.
Burgess	20.	Interview observers; collect, mark and collate verbal data.
Ganczak & Burgess	21.	Plan next run and brief crew.

APPENDIX II

RECOMMENDED THROTTLE REAC ANALOGUE COMPUTER AND EVALUATION STUDIES

Statement of Objectives

1. To provide the flight operator with practice on the throttle configuration (s) to be employed in hot tests, providing a tracking task with some similarity to that required in actual flight.

2. To evaluate throttle configurations on the basis of performance criteria.

Equipment

A throttle handle is mounted on the gas rig shoulder harness for the same essential posture required for right-hand throttle actuation as on the SRLD.

Weight of the thirty-pound shoulder harness at the top of the shoulders should be supported to prevent unrealistic stress.

The flight operator's tracking display would consist of an A-scope marked on the face for altitude reference, with throttle regulation permitting adjustment of a "man" blip. A similarity is provided, in that the actual horizon in flight would be simulated by the altitude reference mark on the scope and the moveable blip would represent the operator.

Procedure

Flight operator (O) gets into gas rig, and weight of rig is supported off his shoulders. The tracking of the scope blip with throttle is begun when the experimenter (E) gives the signal at the altitude reference mark, and holds until signal, then setting the blip back down to zero reference.

The blip automatically begins downward course out of control when simulated fuel expenditure occurs.

Distribution of Practice

Fifteen to thirty minutes a day in practice sessions may be suggested for most efficient learning. Two minute rest intervals between runs, where runs are of approximately 30 seconds duration, is also suggested to offset effects of fatigue.

Criteria

The most pertinent measure to be obtained from simulator flights would seem to be time at which precise target altitude is maintained.

General observations may provide data on other significant parameters of performance. The following data may be recorded for each flight:

Time on Target	Comment on Take-Off Control	Comment on Handling Control	Possible Inadvertent Motion in Pitch	in Roll	in Yaw

Experimental Conditions

To evaluate throttle configurations, such as the grip type vs. motorcycle type, all variables but those of the experimental configuration must be controlled, including the following:

(1) Task instructions to the operator

(2) Effects of practice

(3) Effects of fatigue

(4) Configurations of control

Experimental Variables

The configurations to be experimentally evaluated may include the following:

(1) Grip-type throttle spring return constant.

(2) Motorcycle throttle, no spring return, system friction only.

(3) Motorcycle throttle, light spring return.

Configurations must be recycled for each series of runs, to control effects of practice and fatigue, as follows:

Run Series	Configuration
1	a
2	b
3	c
4	c
5	b
6	a

APPENDIX III

RECOMMENDED STUDY FOR THE SRLD PROTOTYPE SPECIFICATION, LIFTING CONFIGURATION

Statement of the Problem

The present SRLD lifting force is applied at the axillae or arm pits at a small area of concentration. This lifting configuration design was employed to permit maximal body mobility, theoretically required for shifting body c.g. for light control. Moreover, it was considered that since the flight was less than 30 seconds duration, no deleterious effects would occur.

Suspension at the armpits is likely to result in ruptured blood vessels and to hamper circulation to the arms and hands. For training purposes, a longer suspension than 30 seconds may be required. Possible discomfort may tend somewhat to discourage trainees. For this reason, a more optimal configuration in lifting support for comfort may be advisable.

Lifting configurations that may compromise body mobility the least have been discussed as follows:

(1) Banding about the upper portion of the back, e.g., at the latissimus dorsi muscles (see Figure 34), strapped at front such that breathing is least restricted. Weight might then be distributed over a wider area at the axillae and upper trunk while yet maintaining ample body mobility.

(2) Banding about the indentation at the hips just below the iliac crest (see Figure 34). Some proportion of the weight may thereby be lifted, relieving pressure at the axillae, while yet providing ample body mobility.

The general criteria by which these various lifting configurations might be evaluated are suggested below:

(1) Ability of the operator to sense his lift-off or touchdown as a function of the configuration.

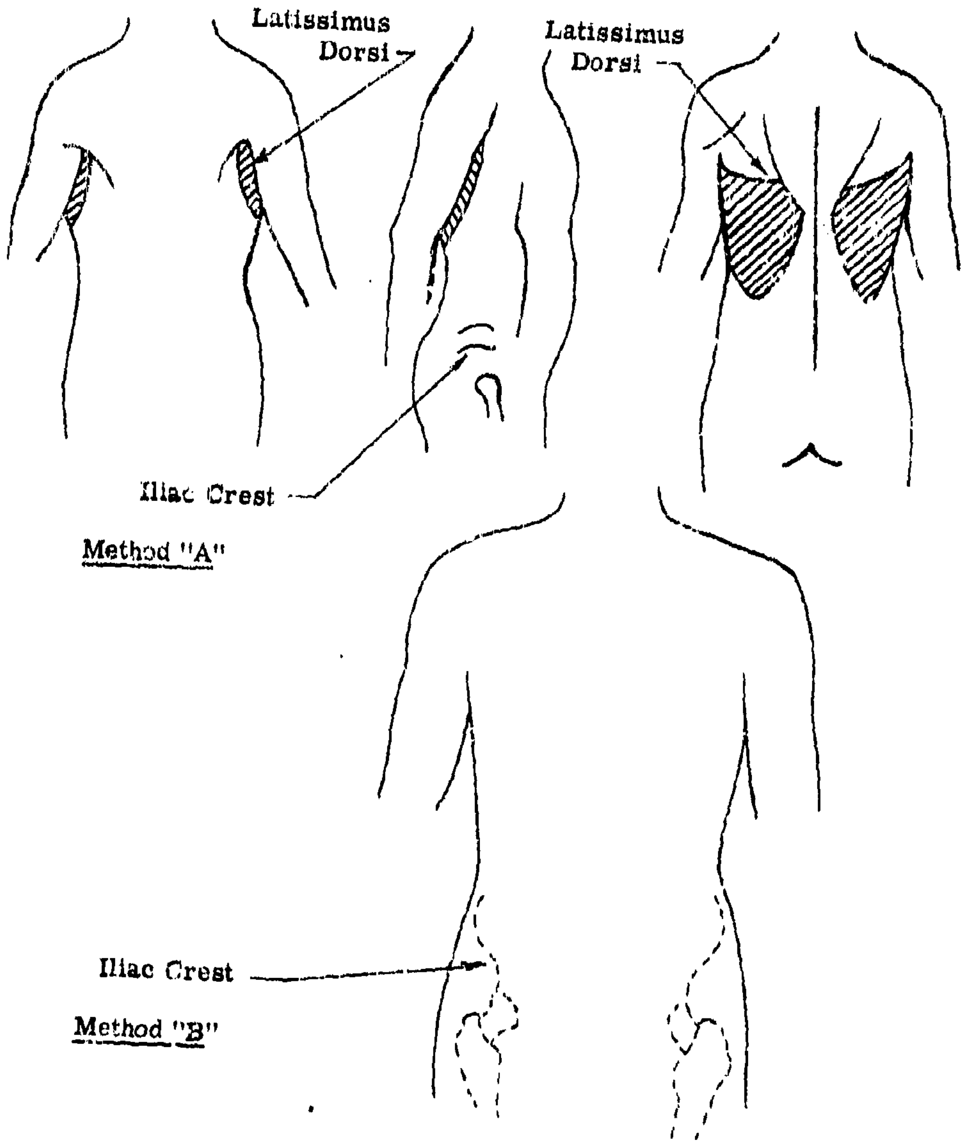


Figure 34. Possible Points of Lift for Improved Lifting Methods

(2) Extent of torso stretch in lift.

(3) Freedom of body motion necessary for control.

(4) Subjective comfort.

The following experimental program is suggested for evaluating these possible lifting configurations and establishing criteria for the prototype model specification.

Required Subject and Test Equipment

Subject (S) wearing loaded configuration, blindfolded attached to lifting tether.

Lifting Configurations

No. 1 Present configuration

No. 2 Heavy belt installed, pulled-in in circumference approximately one inch below the iliac crest.

No. 3 Heavy padded section attached to lifting rings, pulled-in in circumference about the large back muscles and around front above the breast bone.

Procedures

Blindfold S while he rests rig on the SRLD cart. For each trial, S is guided away from cart into test position. Tethering men begin pull at constant rate to lift S off the floor while experimenter (E) observes for "feet off the floor". S calls out "break" the instant he senses that he has broken ground.

E records whether S's response is right or wrong, i.e., feet must be clearly off the ground. If S is off the ground and does not respond instantly, he is given an incorrect check. His response must, in the judgment of the observer, occur precisely when his feet lift off.

Immediately after each trial, S is guided back to the cart and told if his response was right or wrong and in what direction he erred.

Two to three minute rest periods are allowed between each trial for a total of ten trials.

The procedure is repeated for each configuration, and each is recycled to control practice effects, e.g.,

Series No.	Configuration No.
1	1
2	2
3	3
4	3
5	2
6	1

Before changing to the next configuration to be tested, the following procedures would be completed:

(1) S is suspended two feet off the ground while a measure is taken between breast bone and a point just below the pelvis. The amount of stretch from normal is recorded.

(2) S is suspended two feet off the ground while he subjectively evaluates freedom of motion (1) lower limbs in all axes, (2) shoulders, and (3) upper trunk in all axes.

(3) S is suspended two feet off the ground while he demonstrates required flight posture for (1) pitch translation (2) lateral translation, and (3) turning.

APPENDIX IV

ROCKET LABORATORY PRELIMINARY TEST REPORTS

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1 Test No. LD-92 thru LD-____ Test Item SRLD (Pack)

Date 12/14/60 Work Order 6876-000

Test Engineer L. Sileo Test Facility W-1

TEST:

Various thrust level, throttle linkage, and lift tests.

PURPOSE:

To evaluate the throttle linkage and determine the sensitivity of the throttle control.

REMARKS:

The load procedure and run procedure were followed.

During the pressurization of the tanks the pressure rose gradually and slowly.

During firing the pack began to rise toward the ceiling. It rose about 2 to 3 feet off the rest stand. The throttle valve was closed partially and the pack and dummy combination dropped on the rest stand. The throttle valve was opened again and the pack and dummy began to rise. While the pack was rising it began to yaw because of the apparent stretching of one of the guide cables. The pack was landed on the rest stand.

The following recommendations resulted from the run.

1 During the run Mr. Moore noted that the throttle valve was sticking. The 70% detent will be removed and a stiffer spring used to eliminate sticking of the throttle valve.

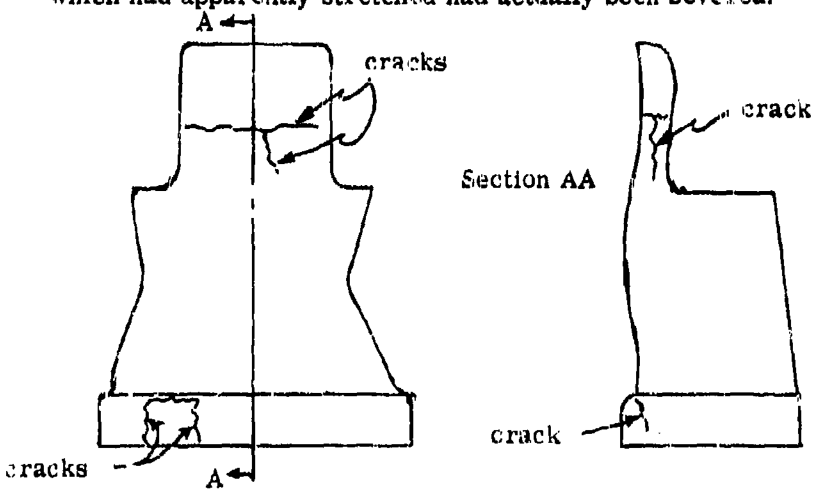
2. Mr. Moore recommended that the warning white flashing light be changed to a red one so it will be visible in bright sunlight. He also recommended that the 2-second flashing intervals and the 1 second flashing intervals be eliminated and that only the last 5 seconds of consistent flashing be used. The warning buzzer signal strength will have to be increased so it can be heard above the sound generated by the nozzles.

3. The nitrogen regulator should be set according to the temperature of the aforementioned regulator.

4. The steam generated by the nozzles obscures the view of the rig, so it was suggested that the floor be kept dry so that the steam formation and condensation would be reduced.

5. The nozzles were aligned only visually, so it was recommended that a nozzle alignment fixture be constructed so that any undesirable thrust components would be eliminated. Such components could cause rolling or yawing of the pack.

Removal of the pack from the stand revealed that the plaster dummy was cracked in several places. The more prominent cracks are shown in the attached sketches. It was also discovered that the guide cable which had apparently stretched had actually been severed.



ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1	Test No. LD-93 thru LD-94	Test Item	SRLD (Pack)
Date	12-16-60	Work Order	6876-000
Test Engineer	L. Sileo	Test Facility	W-1

TEST:

Various thrust level, throttle linkage, and lift tests.

PURPOSE:

To evaluate the throttle linkage and determine the sensitivity of the throttle control.

REMARKS:

Prior to run No. LD-93 the following changes were made:

1. The 70% detent was removed from the control handle and a ball bearing installed in the throttle valve actuator handle to reduce friction.

2. The white flashing light was changed to red. The sequence for the actuation of this light was changed to operate in the last 10 seconds of firing. A flashing light for 5 seconds and a continuous light for the last 5 seconds.

3. A fan was installed in the cell and another outside the cell in an attempt to improve the visibility while running.

4. An RLO was put in work for a nozzle alignment fixture.

5. A new cable was installed in place of the one which was severed on run LD-92.

6. A knotted nylon rope was installed so that it would break any fall onto the rest stand.

7. Minor leaks in the high pressure nitrogen system were eliminated.

8. The portion of the dummy which was almost cracked in two was bolted together.

<u>Run LD-93</u>

The pack would not lift until the end of the run, when it rose about three inches off the rest stand.

The following recommendation resulted from the run: A method should be found to keep the plexiglas shield from fogging up.

Prior to run LD-93 the following change was made. A compound M-S-A-Fog proof was used to keep the plexiglas shield from fogging up.

<u>Run LD-94</u>

The pack would not lift until the end of the run, when it rose about three inches off the rest stand.

The following recommendations resulted from the run:

1. An H_2O_2 sample be taken to determine if the H_2O_2 is within specifications.

2. The 94X regulator be removed and tested.

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1	Test No. LD-95 thru LD-96	Test Item	SRLD (Pack)
Date	12-19-60	Work Order	6876-000
Test Engineer	L. Sileo	Test Facility	W-1

TEST:

Various thrust level, throttle linkage, and lift tests.

PURPOSE:

To evaluate the throttle linkage and determine the sensitivity of the throttle control.

REMARKS:

Prior to run No. LD-95 the following activities were carried out:

1. An H_2O_2 sample was taken from the peroxide drum used to fill the tanks for the last two runs. It was found to be 90.6% H_2O_2 and 98% stabile which is adequate according to the specifications.

2. The 94X regulator S/N 273, the nitrogen filter, and the check valve were removed from the pack. The 94X regulator was replaced with another 94X regulator S/N 257. The check valve was also replaced with another check valve. The nitrogen filter was disassembled to see if it was plugged. It was assembled and reinstalled on the pack.

   The 94X regulator S/N 273 which were removed from the pack was tested. The regulator was leaking. This leakage caused the regulator to act erratic (i.e. on pressurizing the regulated pressure would creep above the desired valve). This valve was subsequently repaired.

3. A short stiff spring improved the operation of the throttle valve.

The tanks were pressurized before the siren was sounded. The H_2O_2 was leaking through the throttle valve and dripping out the nozzles.

When the throttle valve was opened the dummy rose upward and was prevented from going higher by a knot in the nylon cord. The throttle valve control was slowly released and the dummy dropped onto the rest stand. The dummy and pack were quickly brought into the air again, but the dummy and pack combination twisted clockwise loosening the right guide cable. The pack was hovered about one or two feet above the rest stand. The pack was landed after the propellants ran out.

The nozzles by all appearances are not self aligning.

The tanks ran out of propellants while the warning light was flashing.

The length of the run was approximately 26.5 seconds.

Prior to run No. LD-96 the following changes were made:

1. The loosened cable was tightened up.
2. One nozzle was cocked to prevent rotation of the dummy and pack combination.

Run No. LD-96

When the throttle valve was opened the dummy and pack combination lifted off the rest stand. The dummy was set back down onto the rest stand, because the cloud of steam generated was obscuring the view of the pack. The steam cleared away and the dummy was brought all the way up until it was prevented from going higher by the knot in the nylon cord. The dummy was then brought down to about half of its allowable height. The dummy was hovered at this height for a few seconds and then was set down smoothly onto the rest stand.

The following recommendations resulted from this run:

1. The buzzer could not be heard so its strength should be increased or its frequency changed.
2. The dummy should be tied down for the next few runs and the operation of the nozzle controls tested.

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1	Test No. LD-97 thru LD-98	Test Item	SRLD (Pack)
Date	12-20-60	Work Order	6876-000
Test Engineer	L. Sileo	Test Facility	W-1

TEST:

Various thrust level and nozzle directional control tests.

PURPOSE:

To evaluate the nozzle directional control linkage.

REMARKS:

Prior to run No. LD-97 the following change was made.

The dummy was tied down and a remote handle installed to operate the nozzles in the fore and aft directions. The dummy was also weighted down with weights.

Run No. LD-97

When the throttle valve was actuated the nozzles were cycled fore and aft continually until the H_2O_2 ran out of the tanks. The nozzles worked easily during running.

The low frequency of the warning buzzer could not be heard.

The following recommendation resulted from the run.

The nozzle directional control remote handle be removed and the operator stand in front of the dummy and operate the nozzle directly using the pack control handle.

Prior to run No. LD-98 the nozzle directional control remote handle was removed.

Run No. LD-98

The throttle valve was actuated. After the initial blast of steam from the nozzles, Mr. Moore stood in front of the dummy. He operated the nozzle directional control handle until the H_2O_2 tanks were emptied.

It was noticed that the nozzles swivel as easily at full throttle as they do with the throttle valve closed. The operation of the gas generator exhaust produces no ill effects to the skin. The pack while in operation had no heating effects on the operator, Mr. Moore.

Mr. Ganczak who was operating the throttle valve during this run noted that he could just barely hear the warning buzzer.

The following recommendation resulted from the run.

The weights and straps used to hold down the dummy be removed and more flying time be logged in using the throttle valve control.

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN 1 Test No. LD-99 thru LD-102 Test Item SRLD (Pack)

Date 12-21-60 Work Order 6876-000

Test Engineer L. Sileo Test Facility W-1

TEST:

Various thrust level, throttle linkage, and lift tests.

PURPOSE:

To evaluate the throttle linkage and determine the sensitivity of the throttle control.

REMARKS:

Prior to run No. LD-99 the weights and straps were removed so that the dummy and pack combination could rise off the rest stand.

Run No. LD-99

The throttle valve was opened and the pack lifted off the stand. It rose up to the stop (the nylon cord and ring which prevents the dummy from hitting the ceiling). An attempt was made to hover the pack above the rest stand, but it dropped to the rest stand. The pack was again lifted off the rest stand and another attempt made to hover the pack. The pack was landed on the rest stand when the tanks ran out of propellant.

Both cables were stretched during the run.

The light signal was not working correctly possibly because of the cold ambient temperature.

The operator, Mr. Moore, could not hear the buzzer.

When the throttle valve is depressed a lurch is evident as the gas generator suddenly comes up to pressure.

Prior to run No. LD-100 the cables were tightened up.

Run No. LD-100

The throttle valve was opened and the pack rose to a height of one foot. The pack was hovered at this height for a few moments and then hovered at a height of two feet. The pack was dropped onto the rest stand in an attempted controlled landing. The pack was taken all the way up to the stop and then brought down when the propellants were about to run out.

It was noted that the left cable was stretched during the run.

Prior to run No. LD-101 the following changes were made:

1. The allowable travel of the dummy was reduced by lowering the stop in order to prevent further damage to the plaster dummy.
2. A sheet of cellophane was taped to the plexiglas shield to prevent condensation from affecting the visibility.

Run No. LD-101

The throttle valve was opened and an ignition delay was noted. The pack and dummy combination lifted off the rest stand. The pack went up all the way to the stop. In an attempt to hover, the pack came down onto the rest stand. The pack was lifted off again and hovered above the rest stand. The tanks ran out of propellant and the pack was landed on the rest stand.

Prior to run No. LD-102 no changes were made.

Run No. LD-102

The shutoff valve was opened quickly giving rapid pressurization. No adverse effects were noted.

The throttle valve was opened and the dummy began to rise. In attempting to hover, the dummy descended and dropped to the rest stand. The dummy was brought up to the stop. In attempting to hover again, the dummy dropped down and was landed. The dummy was brought up again but the propellant ran out and the dummy was landed.

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Report No. TREC-61-123, November 1961, 176pp. (Contract DA44-177-TC-642), USATRECOM Task 9R38-11-009-14.

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1. Manned Rocket Lift Device
2. Contract No. DA44-177-TC-642

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2. Contract No. DA44-177-TC-642

Bell Aerosystems Company, Division of Bell Aerospace Corporation, Buffalo 5, New York, SMALL ROCKET LIFT DEVICE - PHASE II TESTING OF THE ASSEMBLED UNIT. W. F. Moore, J. Kroll, J. Burgess et al.

Report No. TREC-61-123, November 1961, 176pp. (Contract DA44-177-TC-642), USATRECOM Task 9R38-11-009-14.

Unclassified Report

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Static firing, tethered and free-flight test results are presented. Stability and control REAC simulation data is compared with flight test results. Free-flight tests were highly successful. The feasibility of the man-rocket concept was proven. Recommendations are made to continue flight testing to improve several aspects of the design and to obtain quantitative stability and control data to enable establishment of system prototype specifications.

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