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major achievements in BIODYNAMICS: Escape Physiology at the Air Force Missile Development Center

Holloman Air Force Base, New Mexico

1953 - 1958

Historical Division
Office of Information Services
Air Force Missile Development Center
Air Research and Development Command
Holloman Air Force Base, New Mexico

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BIODYNAMICS: ESCAPE PHYSIOLOGY

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AIR FORCE MISSILE DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE

COLONEL JOHN PAUL STAPP

FOREWORD

Since its inception a half-century ago, the United States Air Force has constantly operated higher and higher, faster and faster, until it has all but shattered the barriers of physical forces and alien physical environments which throughout all history have confined the activities of man to the immediate vicinity of the earth. With every advance in velocity and altitude resulting from new types of high-performance aircraft, rockets or satellites the potential operational environment of the Air Force has expanded until today the actual area of operations extends to the very borders of interplanetary space and the immediate potential includes the vast central portion of the solar system. And with every advance of the environmental parameters, man encounters physical and biological hazards unique in his experience.

For many years scientists in the Biodynamics and Space Biology Branches of the Air Force Missile Development Center's Aeromedical Field Laboratory have sought to identify and understand the nature and extent of these hazards, and to perfect protective devices and techniques for the benefit of man operating at high altitudes within the atmosphere and in the limitless space beyond. In the study here presented, Dr. David Bushnell of the Center's Historical Office has carefully documented that portion of this effort which has explored the punishing effects of windblast and the tremendous forces of abrupt deceleration encountered during emergency escape from high-mach aircraft. He has also mentioned the application of this experimentation to the effects of the magnitude and relatively long duration of g-loading experienced during sustained acceleration of multistage space vehicles.

This monograph is the fourth of a projected series of six related to the contributions of Holloman's Aeromedical Field Laboratory. Others already published are <u>The Beginnings of Space Biology at the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, 1946 - 1952</u>; <u>Major Achievements in Space Biology at the Air Force Missile Development Center, Holloman Air Force Base New Mexico, 1953 - 1957</u>; and the <u>History of Research in Subgravity and Zero-g at the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, 1948 - 1958</u>.

With pleasure, Dr. Bushnell wishes to acknowledge the cooperation in making this study which he received from members of the Aero Medical Laboratory and the Historical Division at Wright Air Development Center, and officials of the Directorate of Life Sciences at Headquarters, Air Research and Development Command. The staff of the Aeromedical Field Laboratory at the Air Force Missile Development Center, as always, willingly

placed its entire files at his disposal and has assisted patiently many times in helping to interpret certain scientific findings. Any error in fact or interpretation, however, unless otherwise cited, is solely that of the Historical Office.

James Stephen Hanrahan
Center Historian
June 1958

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During recent years the Air Force Missile Development Center has made important contributions to the Air Force human factors program in two broad fields: space biology and biodynamics. Under the heading of space biology, it has been engaged in research on biological effects of cosmic radiation, on sealed cabin environment, and on subgravity, all of which have been discussed in previous historical monographs.[1] Under the heading of biodynamics---which can be defined as the study of the effects of mechanical forces on living tissues---its research efforts cover a variety of problems ranging from the merits of automotive seat belts to patterns of deceleration in space flight. At first glance, some of these problems of biodynamics have little in common. In each case, however, the research program is centered around a unique Holloman complex of test facilities, of which the 35,000-foot high-speed test track is only the best known example. Moreover, each of the various research tasks in biodynamics is in some measure an outgrowth of the deceleration and windblast studies which began at Holloman Air Force Base in 1953 under the direction of

Doctor (Lieutenant Colonel and later Colonel) John Paul Stapp, and which were related primarily (though not exclusively) to the problem of escape from high-performance aircraft.

The research project that Colonel Stapp personally brought to Holloman when he came to assume command of the Center's Aeromedical Field Laboratory in April 1953--Biophysics of Abrupt Deceleration--was specifically oriented toward the study of high-speed escape from aircraft. The escape problem remained one of the most important research topics of Project 7850, Biodynamics of Human Factors in Aviation, that was drawn up in 1954 to supplement and in large measure to supersede the former project. Research on this same theme has been reoriented but by no means eliminated since March 1958, when Project 7850 was rewritten as Biodynamics of Space Flight. And it was a series of experiments directly related to escape physiology, Colonel Stapp's own rocket-sled rides on the Holloman track, that first brought nationwide attention to the Holloman aeromedical organization.

The high-speed escape problem was one of imposing magnitude. A pilot bailing out at transonic or supersonic speed had to face first the ejection force required to get him out of his plane, then the sudden onslaught of windblast and wind-drag deceleration, likely to be followed by dangerous tumbling and spinning. Any one of these forces taken separately was a potential cause of injury or death, not to mention the anxiety on the part of aircraft pilots who did not know if they would survive or not in case of ejection. For, at the time research on this problem at Holloman began, the escape systems available were either admittedly inadequate or of unproven worth for aircraft having performance capabilities above mach one in speed and 45,000 feet in altitude.[2] Since aircraft with this range of performance were already in existence, and were destined to assume ever greater importance in the Air Force inventory, there was a glaring need for reliable data on human tolerance to all the forces that could be encountered in escape at the indicated speeds and elevations. The fact that such information was not already available was another case of the lag, often deplored by aero-medical scientists, between aircraft design and human factors research.[3]

Test Directive 5200-H1 for Biophysics of Abrupt Deceleration, dated 15 April 1953, proposed to remedy this situation at least in part, setting forth as its objective:

> A program of experiments with the High Performance Linear Decelerator to study tolerance and survival limits for (1) Linear Deceleration, (2) Wind-blast in a Linear Deceleration Field, (3) Tumbling in a Linear Deceleration Field, and (4) Linear Deceleration with Tumbling and Windblast, as factors of the problem of escape from high speed, high altitude aircraft.... Recommended limiting values established by these experiments will determine the design of escape devices and the choice of ejection seats or of ejection capsules for a particular aircraft.

This test directive, with later amendments, was the official basis for Colonel Stapp's research at Holloman until Project 7850 became fully operative early in 1955. It stated further that the "current military need" was to study tolerance to deceleration up to fifty-five g's, but this figure was subsequently revised,[4] and all such figures were naturally for rough guidance only. In any case, the maximum number of g's was only one of the factors involved in this study. Not only were tumbling and windblast to be explored, as stated in the directive, but also the rate of onset and duration of g-forces would be considered as affecting the total deceleration that a human body can withstand. The research assignment was thus arduous and complex, but, as Colonel Stapp once stated in a slightly different connection,

> ....one factor is encouraging. There are only two models [male and female] of the human body currently available, with no immediate prospects of a new design; any findings in this research should provide permanent standards.[5]

In his own previous experiments on the 2,000-foot deceleration track at Edwards Air Force Base, California, Colonel Stapp had already experienced forces up to roughly 46 g's at 500 g's per second rate of onset. Both this experiment and one in which a co-worker withstood over 38 g's at 1370 g's per second produced definite signs of shock but no permanent ill effects. Colonel Stapp also directed chimpanzee tests while at Edwards, exposing the animal subjects to plateaus of 65 g's, rates of onset of approximately 3400 g's per second, and peaks of about 150 g's, without finding the lethal point or even the point of irreversible injury. However, the duration of decelerative forces was always very short. Durations ranged from .15 to .42 second in the human experiments, which attained a top speed of only 226 feet per second; and there were no experiments on deceleration combined with windblast and tumbling.[6]

Thus the Edwards tests did not adequately answer the questions posed in the project Biophysics of Abrupt Deceleration. They clearly suggested that the human body, if properly positioned and secured, could endure any aircraft crash forces in which the aircraft itself survived,[7] but they did not duplicate the conditions of high-speed escape. For the latter purpose the Holloman high-speed track, originally built in 1949 as a rail launcher for the Snark missile, was especially well suited. It was 3550 feet long (before the first of a series of track extensions) and was fully instrumented. It also had a water braking system as compared with the mechanical friction brakes used on the 2000-foot Edwards deceleration track. The water brakes permitted both high deceleration forces and a wide range of duration and rate of onset.[8]

Deceleration and Windblast Experiments on the Holloman Track

The Holloman track had previously been used for captive testing of missiles and their components, but until Colonel Stapp's arrival had never been used in biophysical research. To be sure, Colonel Stapp did not take a high-speed ride on the track himself until he had been at Holloman almost a year. First he had to wait for the sled, known as Sonic Wind Number 1, which was specially constructed for his test program by Northrop Aircraft, Incorporated; then the sled and track equipment had to be put through a series of practice runs starting 23 November 1953. The first run with a living subject--a chimpanzee--took place on 28 January 1954.[9]

On 17 March, finally, Headquarters, Air Research and Development Command gave its authorization to conduct human runs;[10] and on 19 March Colonel Stapp was strapped in for his first Holloman sled ride. Apart from testing the feasibility of the equipment for human experiments, the objective of Colonel Stapp's first ride was to "evaluate human reaction to exposure to about 15 g of linear deceleration for about 0.6 seconds duration, approximately double the duration possible for the same magnitude of force on the crash decelerator previously used at Edwards...."[11] The run was essentially successful, reaching peak velocity of 615 feet per second and up to twenty-two g's deceleration, with only momentary ill effects.[12]

A second human experiment took place on 20 August, with Colonel Stapp again serving as subject. This test was primarily to explore the effects of abrupt windblast, which had not been a factor in the previous test because of a solid panel windshield installed on the sled. A special helmet was devised, completely covering the head, by Dr. Charles F. Lombard of Protection, Incorporated, a division of the Mine Safety Appliances Company. At the same time, to provide the abrupt exposure required, the sled was equipped with

> ....a rectangular frame holding two doors hinged to the sides which opened inward by outside wind pressure when a cam mounted at the selected point on the track tripped a mechanism releasing the catches. Abrupt impingement of windblast against the subject through the 34.5 by 62.50 inch opening thus provided would simulate the effect of jettisoning an aircraft canopy.[13]

This mechanism had first been tested with a chimpanzee run on 9 April, when only one door opened, but it had undergone additional tests since then, and on the 20 August run it functioned as scheduled. Colonel Stapp was exposed to an estimated maximum of 5.4 pounds per square inch of wind pressure, with maximum velocity of 736 feet per second and peak deceleration of only 12 g's. He suffered no apparent ill effects save temporary and quite minor injury from flapping clothes and wind-blown grains of sand. It was, he said, the "easiest" of all the runs he had made so far.[14]

During September 1954 the principal sled experiment was one that made use of a tumbling seat attached to the rocket sled in order to evaluate the effect of tumbling in comination with deceleration and windblast. The tumbling seat had been tried out before in static tests, and in one prelimary test on a moving sled; but the first full-scale experiment was held on 14 September. A chimpanzee was spun at the rate of 105 revolutions per minute at the same time as it was being exposed to sudden windblast (through the same opening windshield used on Colonel Stapp's previous run) and to braking deceleration that reached a peak of forty-five g's; yet the subject came through very nicely.[15] This type of experimentation supplemented research done elsewhere on the effects of pure tumbling, for instance on a spinning turntable, but with its fixed axis of rotation the tumbling seat did not wholly simulate free-fall tumbling as encountered during escape from aircraft. Moreover, known instances of tumbling in the thin air at high altitudes all suggest that rapid tumbling must be eliminated if at all possible. And it largely can be, by means of stabilizing devices. For all these reasons the Aeromedical Field Laboratory has not continued its tumbling seat experiments, but instead continued work on deceleration and windblast both separately and in combination with each other.[16]

The month of September also saw the first testing, with a chimpanzee subject, of a new device for producing abrupt wind-blast--a windshield that could be jettisoned explosively at a given point during the run. Unfortunately, the jettisonable windshield inflicted quite a bit of damage on chimpanzees, causing the death of more than one, before this method finally proved its value.[17] During October Colonel Stapp went to California, where he performed an autopsy on a Northrop test pilot believed to be the first person who had actually ejected from an aircraft at supersonic speed. For his own research on human tolerances Colonel Stapp was interested to learn whether the pilot had suffered any major harm from windblast, tumbling, and deceleration. He could find none, concluding that the fatal injuries were due to being struck by the tail surface of the plane.[18]

Much of the activity of the Aeromedical Field Laboratory in the autumn of 1954 consisted of preparations--including chimpanzee control runs at 600 miles an hour and faster[19]--for the most memorable of all Colonel Stapp's rocket sled rides, the one of 10 December 1954. This test was designed to explore both deceleration and windblast, but there was no attempt to simulate abrupt onset of wind pressure. The jettisonable windshield was still unreliable, and the swinging-door system used in August weighed too much for the sled to attain desired velocity. Hence no windshield at all was used. Colonel Stapp merely wore the helmet he had used in August, completely covering his head, and saw to it as before that his arms and legs were well secured against flailing, which was one effect of windblast already known

Colonel Stapp Preparing for 10 December 1954 Sled Run to induce injuries in actual escape from aircraft.

The run itself reached a maximum speed of 937 feet per second, or mach .9. This was fast enough for the sled to overtake and pass a T-33 aircraft that was flying overhead. Windblast was as high as 7.7 pounds per square inch, or better than 1,100 pounds per square foot, and water brakes brought the sled to a stop in just 1.4 seconds from maximum velocity. Rate of onset of deceleration was 600 g's per second, reaching a plateau of twenty-five g's and over for more than a second, with peaks of thirty-five and forty g's. The jolt Colonel Stapp received has been compared with that "an auto driver would experience were he to crash into a solid brick wall at 120 miles per hour."[20]

As was to be expected, this time Colonel Stapp showed much more obvious effects of his ride. There were some strap bruises and the usual blood blisters from grains of sand, but in addition he suffered extremely painful effects on the eyes. In Colonel Stapp's own words, on entry into the water brakes his vision became a "shimmering salmon," followed by "a sensation in the eyes...somewhat like the extraction of a molar without an anesthetic."[21] This one aspect of the experiment, which was due purely to deceleration and not to windblast, overshadowed all other minor injuries and physical sensations during and after the run. Yet not even the eyes suffered any long-range or irreversible damage. Colonel Stapp's experience left him with two black eyes, which lasted the usual length of time, but vision returned in about eight and a half minutes. To use his own words once again,

> There was no fuzziness of vision or sensations of retinal spasms as had been experienced in 1951 following a run [at Edwards] in which a retinal hemorrhage occurred. Aside from congestion of the nasal passages and blocking of paranasal sinuses, hoarseness and occasional coughing from congestion of the larynx, and the usual burning sensation from strap abrasions, there was only a feeling of relief and elation in completing the run and in knowing that vision was unimpaired.[22]

As soon as possible after his admission to the base hospital, where he went for further examination, Colonel Stapp "ate heartily and spent two hours accommodating demands of motion picture photographers making documentary coverage of the run."[23]

What the run proved, essentially, was that windblast on a properly secured and protected body at over 600 miles per hour and at 4100 feet above sea level--equivalent to mach 1.6 at 40,000 feet--[24] was "negligible and unnoticeable in comparison with deceleration effects of G plateaus of more than 25 gs for 1.1 seconds."[25] This duration was the longest yet attained for such high g-forces, but the deceleration, too, was shown to be humanly tolerable. Moreover, it "exceeded any predicted g time pattern for high speed aircraft ejections."[26] Although acceleration effects were not a primary object of study, the run also demonstrated that acceleration exceeding six g's for more than three seconds, as attained in the first phase of the run, could produce brief visual blackout but again no serious injury--in fact nothing that would hamper a pilot exposed to similar thrust in high-speed catapult or jet-assisted takeoff from "taking over control of the aircraft within several seconds after launching."[27]

One other result of the 10 December experiment--and to a lesser extent of Colonel Stapp's two previous rides on the Holloman high-speed track--was to give the Air Force doctor a measure of popular renown as "the fastest man on earth" that was comparable to the esteem he already enjoyed among aeromedical scientists. His sudden emergence as a national hero led to a spate of television appearances, including one with Ralph Edwards' "This is Your Life," which required him to be mysteriously called away to Los Angeles from a conference he was attending on the east coast.[28] His portrait appeared on the cover of Time, and for obvious reasons it was news throughout the nation when the "fastest man" was cited by the Alamogordo, New Mexico, police for speeding at forty miles an hour (unspecified rate of onset) in a twenty-five-mile zone. However, the Justice of the Peace before whom he appeared managed to divert part of the publicity to himself by dismissing the charge against Stapp, issuing a new citation against a fictitious "Capt. Ray Darr," and paying the fine from his own pocket.[29]

Then, too, Colonel Stapp's famous ride was reproduced, in a fictional and somewhat romanticized version, as part of the Twentieth Century Fox motion picture "Threshold of Space." This picture was partially filmed at Holloman, where a number of special sled runs were staged in the fall of 1955 in cooperation with the film company. Likewise an advance showing of the picture itself was held at the Holloman base theater, on 2 March 1956, with a collection of Hollywood stars imported for the occasion.[30]

On a more serious level, Colonel Stapp received many additions to his already substantial collection of honors and awards. Among these were the Air Force's own Cheney Award, granted yearly "for an act of valor, extreme fortitude, or self-sacrifice in an humanitarian interest performed in the preceding year...," which was personally given to him in August 1955 by General Nathan F. Twining, Chief of Staff. He also received an Oak Leaf Cluster to the Legion of Merit award he held before. An honorary Doctor of Science degree from Baylor University, his alma mater, was granted in May 1956 during the same ceremony in which an honorary degree was given to President Dwight D. Eisenhower. In November 1957, Colonel Stapp obtained the $1,000 Service Award offered by the Omaha Mutual Benefit Insurance Company, of which he was the third recipient. There were many other awards and citations, too, and of course they were not based solely on the rocket sled experiments performed at Holloman in 1954. Colonel Stapp's achievements before coming to Holloman were naturally taken into account when he received professional or scientific recognition, and so was all his other work in directing the Aeromedical Field Laboratory since 1953.[31]

In some respects national prestige was almost a disadvantage. Brigadier General Marvin C. Demler, Deputy Commander for Research and Development, Air Research and Development Command, at one point raised a "military objection" to Colonel Stapp's participation in a professional gathering on the ground that public appearances (both professional and otherwise) were causing "dissipation of his time into non-research and development efforts...." The message signed by General Demler counted sixty-two "known" appearances in roughly the first eight months of 1956.[32] Close contact with researchers elsewhere was, of course, extremely valuable for the Aeromedical Field Laboratory's program; yet Colonel Stapp himself calculated that in the second half of 1956 trips and appearances kept him away from the Laboratory for more time than he was actually present.[33]

Fortunately, Colonel Stapp managed somehow to proceed with his research despite such distractions. In fact he had scarcely recovered from his ride of 10 December 1954 before he was speaking of his desire to make another human experiment in the future at supersonic speed. What he had in mind was a sled ride at about 1,000 miles an hour, designed primarily to explore tolerance to windblast as such rather than windblast combined with deceleration. Colonel Stapp suggested that a longer track would be needed both to develop such speed and to have enough room to come to a stop without the decelerative forces completely overshadowing those of windblast; and a likely candidate was the 4.1-mile "SNORT" or Supersonic Naval Ordnance Research Track at China Lake Naval Ordnance Test Station, Inyokern, California.[34]

However, Colonel Stapp has not yet taken his supersonic sled ride. He was even startled in June 1956 to read in the newspapers that he had been "grounded" from any future high-speed runs on the basis that he was too valuable for the Air Force to risk. The grounding statement was attributed to the same General Demler who shortly afterward "grounded" Colonel Stapp from attending a professional meeting. But in actual fact General Demler's remarks were somewhat overplayed in the press. Admittedly, command headquarters did not look with much favor on the possibility of another sled ride by Colonel Stapp, but he did not receive official notification of being "grounded,"[35] and he merely proceeded--as before--on the assumption that no further high-speed experiment with himself or any other human subject would be made without first carefully weighing all the advantages to be gained by it and receiving specific command approval. Until more preliminary tests were conducted, without human subjects, no concrete plans for another such human experiment could even be discussed.[36]

Chimpanzee tests, at any rate, have been continuing at regular intervals since December 1954. Within a week after Colonel Stapp's famous ride a chimpanzee went down the Holloman high-speed track for another test of the jettisonable windshield, which this time failed to jettison at all. Early in the following year a series of sled runs was held to explore the effect on chimpanzees of abrupt windblast in combination with forty-g deceleration for various durations. The stated objective was "to evaluate the exact transition point from purely impact effects to circulatory effects typical of centrifuge." Speeds were comparable to that attained by Colonel Stapp, and windblast effects were again negligible. The results also indicated that a chimpanzee could take forty g's for four-tenths second without critical injury, although they were inconclusive concerning longer exposure.[37]

Since the spring of 1955 both deceleration and windblast studies on the Holloman high-speed track have attained progressively higher values, but they have also followed increasingly separate lines of development. In the case of deceleration experiments, a number of sled runs were held from April through June 1955 with a drop seat mounted on the sled to explore the combination of vertical with horizontal deceleration.

Windblast was not a serious factor in these tests, which were actually concerned with aircraft crash forces rather than high-speed escape. This type of experimentation will therefore be considered in a separate monograph related to other accomplishments in biodynamics at the Air Force Missile Development Center.[38]

Tests designed specifically for horizontal (transverse) deceleration were resumed on 31 August 1955 with another forty-g experiment. Later tests in November 1955 and March 1956 subjected chimpanzees to eighty g's of programmed deceleration, with rates of onset exceeding 4000 g's per second. Tests were then interrupted for about a half year, while the sled itself was reconstructed following an accident in which it became airborne, and also while the track was lengthened to 5000 feet. This extension was justified primarily for aeromedical research, was funded through an emergency allocation to the Aeromedical Field Laboratory and permitted the attainment of significantly higher speeds with even the relatively heavy sled Sonic Wind Number 1. Deceleration runs began again, on the 5000-foot track, in October 1956, and fifteen were conducted from then through the following March. Subjects were exposed to peak decelerations above 200 g's, with rates of onset ranging as high as 16,800 g's per second.[39]

These figures, obviously, far surpassed the limits of voluntary tolerance, and far surpassed any conceivable g-forces that might be encountered in high-speed escape from aircraft. Indeed, deceleration tests on the high-speed track since the summer of 1955 have been more concerned with pure research on deceleration forces than with any single applied research problem. Hence these experiments, too, will require further discussion in a later monograph.

Specialized Windblast Studies, 1955-1958

Even by the end of 1954 a significant amount of data had been accumulated on tolerance to the forces of wind-drag deceleration encountered in high-speed escape from aircraft. With the use of adequate restraint these forces appeared humanly tolerable, to judge from Colonel Stapp's experiments, and escape system designers could plan accordingly. But it was not clear that the effects of windblast as such in high-speed escape would be similarly tolerable. Windblast encountered on Colonel Stapp's memorable ride did not even approach the maximum that might be expected in actual escape situations.[40]

The later deceleration runs from August 1955 through March 1957 did not use any sort of windshield, and therefore they also exposed test subjects to relatively high windblast. Once the track was lengthened, the deceleration sled reached velocities roughly as high as 775 miles an hour, or slightly over mach one.[41] Yet not even this increase in speed was enough to duplicate the maximum windblast possible in escape from high-performance aircraft. Certainly the windblast produced on these runs did not cause major ill effects, especially as the test subjects were well secured and used a type of face mask; in any case, windblast effects were bound to be overshadowed by the extreme g-forces experienced on the very same runs. Accordingly, as early as May 1955 the Aeromedical Field Laboratory began a series of tests carefully planned so that supersonic windblast as such, not deceleration, would be the primary interest. Unlike the later deceleration tests, these very clearly fell within the scope of research on high-speed escape from aircraft.

Specialized study of windblast effects was in accord with the April 1953 test directive for Biophysics of Abrupt Deceleration, which called for data on windblast alone as well as windblast in combination with deceleration. It was also foreshadowed by the theoretical organization of Project 7850, Biodynamics of Human Factors in Aviation, since a separate Task 78505, Tolerance to Abrupt Windblast, was included in the original project development plan. Major Joseph V. Michalski, who was also Chief of the Aeromedical Field Laboratory's Biodynamics Branch in 1954-1955, was listed as the original task scientist. Moreover, in the spring of 1955 the Laboratory received a new high-speed sled, Sonic Wind Number 2, which was specifically designed for windblast studies. It was lighter than Sonic Wind Number 1, and therefore capable of exploring windblast at supersonic speeds even within the original 3550-foot track length. Weight was saved by designing the sled for performance only at "25 g with a safety factor of 1.5."[42]

Fifteen runs were made at Holloman on the 3550-foot track with Sonic Wind Number 2 from 17 May 1955 through 2 March 1956. In three cases anthropomorphic dummies rode the rails, but otherwise chimpanzee subjects were used. Tests were planned with ejectable windshield, with no windshield, and also (for certain sled-performance and control tests) with a fixed windshield. The top speed attained on a single run was 1445 feet per second, which was about mach 1.3 or just short of 1000 miles an hour. This happened to be a control run with fixed windshield, but on other runs, with animal subjects exposed to windblast, the sled reached velocities up to roughly 1350 feet per second and encountered wind pressure well above 2000 pounds per square foot. This compared with 1107 per square foot sustained by Colonel Stapp in December 1954. It was also more than the estimated 1280 pounds per square foot encountered in February 1955 by test pilot George Smith, at mach 1.05 and 6500 feet, in the first definitely recorded instance of survival in supersonic escape. G-forces were comparable to or slightly greater than on Colonel Stapp's last ride, but the fixed-windshield control runs helped isolate any effects due solely to acceleration or deceleration forces.[43]

None of these experiments found what could be called a tolerance limit for windblast, much less the lethal point. Different chimpanzees suffered varying degrees of injury, mostly minor, depending on the type of harness and protective covering worn, but there was no indication that even the highest level of windblast experienced so far was necessarily injurious to a properly secured and protected subject. The next step was to develop still greater sled velocities, and the extension of the Holloman track to 5000 feet should have helped somewhat. However, the extension was not yet finished when still another construction project was started, this time designed to lengthen the facility to 35,000 feet, which would make it the longest in the world, and also to replace existing rails with continuous-weld track. The 35,000-foot track would not be ready for many months, and though the construction work did not at once put an end to test activities, it did seriously interfere with them. In these circumstances Colonel Stapp and his associates simply transferred the windblast test operations (and the sled Sonic Wind Number 2) to the Supersonic Naval Ordnance Research Track at China Lake.[44]

Colonel Stapp's principal collaborator for the forthcoming

China Lake tests was Doctor (Captain) John D. Mosely, who arrived at Holloman in the latter part of 1956 and was made Chief of the Biodynamics Branch as well as task scientist for Task 78505, Tolerance to Windblast. Captain Mosely's first windblast test, on 18 February 1957, was the first at China Lake and also the first high-speed track experiment since 2 March 1956 that was primarily designed for windblast. It was a checkout run, reaching a velocity of 1,333 feet per second. The first full-scale experiment came on 13 April, with very moderate acceleration and deceleration but a peak velocity of 1,945 feet per second (about mach 1.7). The chimpanzee subject wore a special flying suit devised by the Aeromedical Field Laboratory and a helmet developed by Protection, Incorporated. Unfortunately, the headrest failed even before the sled reached supersonic speed, the helmet failed in turn, and the head was yanked so violently as to break the subject's neck. There was some burned tissue due to windblast, but chiefly the run underscored the danger that exists from flailing if the subject is not adequately secured.[45]

The next run at China Lake was held on 27 June, and reached 1,905 feet per second, with a duration of two seconds at roughly mach 1.7. Maximum windblast was about 3,500 pounds per square foot. The test again resulted in the subject's death, but this time it occurred twenty-four hours after the run, and the cause

Captain John D. Mosely

was different. The chimpanzee was adequately secured against flailing, but helmet and clothing proved unsatisfactory; the flying suit tore and exposed the subject to serious burning from windblast. Roughly forty per cent of the body was covered with second and third degree burns. The chimpanzee at least fared better than certain guinea pigs attached to the same test sled by the Bio-Acoustics Branch of Wright Air Development Center's Aero Medical Laboratory. Two guinea pigs were attached merely with nylon netting, and the third was placed in a metal container whose largest opening measured one inch by two inches. The can itself stood up through the test, but all three guinea pigs vanished into thin air.[46]

Colonel Stapp and Captain Mosely were confident that just as the flailing that had lethal effect in April was prevented in June, the burning encountered in the June test could likewise be avoided. Dacron sail cloth used for strap material did not fail in the June run, suggesting that an entire suit made from the same cloth might provide the necessary protection. When the next test in the series took place on 12 March 1958--with speed and windblast about the same as before--a suit of the new material did prove satisfactory. Once again the subject was lost, because of a harness failure that in turn caused the helmet to come off, but it is hoped that this, too, will be prevented on the two remaining tests that are planned in the present windblast series.

On the last three tests wind pressure still did not reach the highest levels conceivable in an operational escape situation. Even so, the levels attained are impressive, especially when it is kept in mind that for flight at higher altitudes than China Lake (elevation 2,218 feet) the air density and thus potential wind pressure for any given speed will naturally be less. It was even possible, in a sense, to take encouragement from the fact that damage from windblast was no worse. Then, too, some real progress has been made in devising means of protection, which further underscored the possibilities for adapting an open escape system, such as the ejection seat, for use with advanced supersonic aircraft. As Colonel Stapp has pointed out, the greatest advantage of a completely enclosed system--that is, of an escape capsule--is simply the elimination of windblast, since the problems of tumbling and deceleration must be met in either case.[47]

To be sure, not everyone agrees with this line of reasoning, and more will be said on the arguments for and against different escape systems toward the end of this study. However, it was not the role of the Aeromedical Field Laboratory to dictate the design of escape systems. Its role was to provide experimental data on which final decisions could be based, and from this standpoint the windblast experiments will have fulfilled their objective no matter what the final test results may be.

It is worth noting that the Holloman laboratory received excellent cooperation from the Navy for its series of China Lake sled runs. When unexpected delays arose during preparations for the June 1957 run, certain tests relating to high-priority missile development were temporarily "bounced" in order to hold the track for the Aeromedical Field Laboratory. On the other hand, operations at China Lake could be a rather expensive proposition. Quite apart from the cost of moving people, equipment, and chimpanzees to California, Colonel Stapp had been quoted an estimate of $75,000 for use of the Navy track on five test runs; but the first run alone took more than a third of this amount. Because of bookkeeping technicalities the second run, on 13 April 1957, was much cheaper even though it happened to fall on a Saturday. Weekend testing required payment of overtime to employees but did not saddle the Air Force with a large share of base overhead.[48]

For various reasons the March 1958 run was cheaper still--but it will be the last at China Lake. The remaining tests in the current series will be conducted on the newly-completed 35,000-foot track at Holloman. They will also be conducted by Captain Mosely without the assistance of Colonel Stapp, unless he returns for the occasion from Wright Air Development Center, where he went to assume direction of the much larger Aero Medical Laboratory in April 1958.

After that the task program will continue to use the local test facilities, but it will undergo a definite reorientation. The windblast task of Project 7850 (Task 78505) has been renamed Tolerance to Ram Pressure and Thermal Effects in line with the general revision of Project 7850, which is now entitled Biodynamics of Space Flight. Thus in future the problem of escape from aircraft--meaning principally escape from high-performance aircraft at low or medium altitude--will no longer be the primary concern of Task 78505. The latter will have more to do with problems of flight through the upper atmosphere (120,000 feet or higher) and in space, including emergency escape from a manned vehicle re-entering the atmosphere.[49]

Other Work on the Escape Problem

Although high-speed track studies of windblast and deceleration have been the main Holloman contribution to research on the escape problem, they do not represent the Center's entire effort. Another unique Holloman facility that has been used for this research is the 120-foot short track, or Daisy Track as it is usually called. This track was completed in 1955, precisely for aeromedical research, and is operated under the general auspices of Task 78503 (of Project 7850), Tolerance to Impact

Forces. The Daisy Track is a versatile research tool, and its performance range has nicely supplemented that of the more famous long track. The majority of the work related to its use will be described in detail in a later monograph, since its purpose is to accumulate basic research data on human tolerance to as broad as possible a range of g-forces, in all planes of body orientation, rather than to support a particular program of applied research. However, data acquired on the Daisy Track are relevant to a great many specific research problems, of which not the least has been the problem of escape from aircraft. From the viewpoint of anyone who must deal with that problem, obviously, the more data become available on g-tolerances, the less room there is for guesswork in what is a matter of life or death.

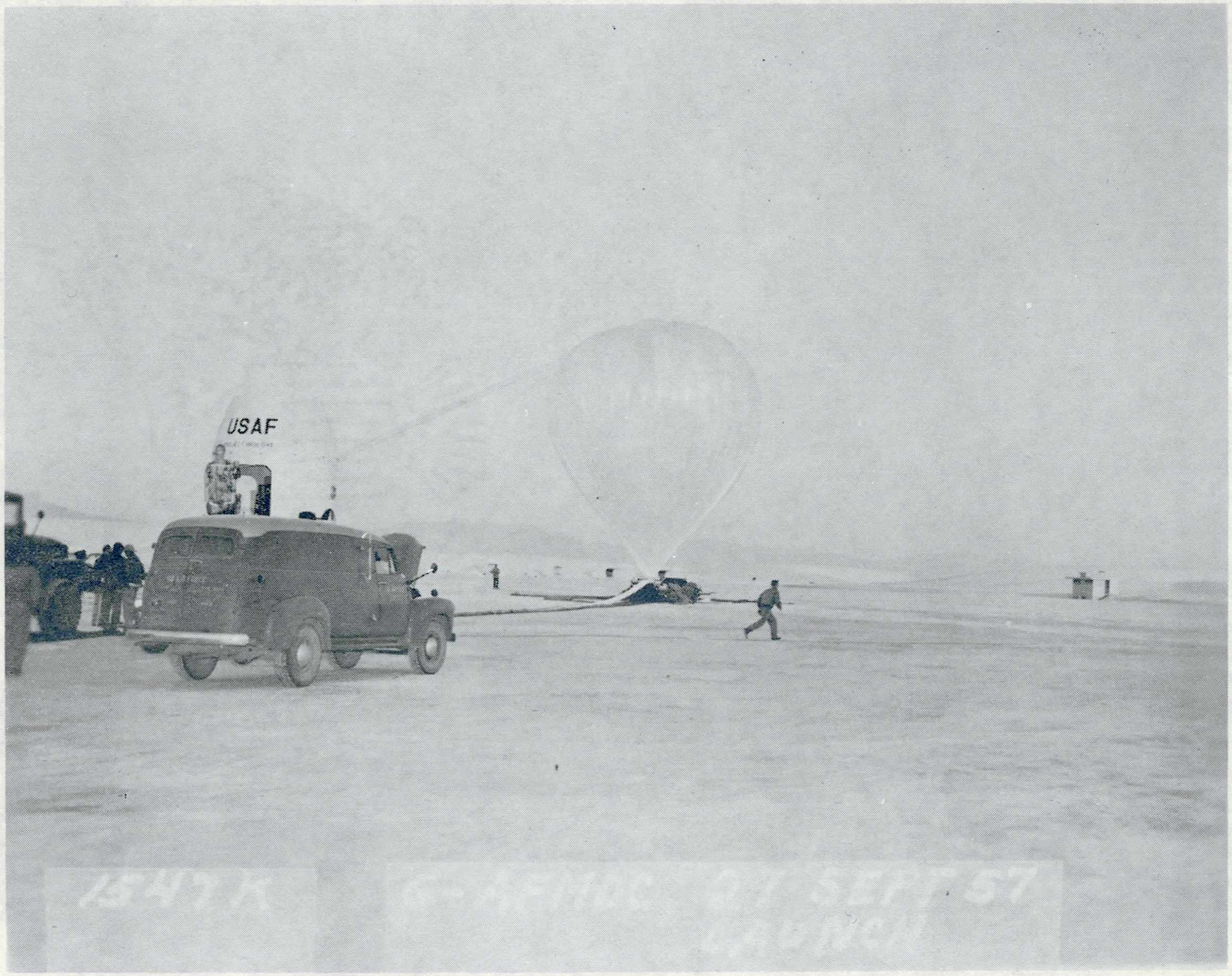
Colonel Stapp's experiments on the long track supplied data on tolerance to deceleration such as a pilot encounters from wind drag following actual ejection from the aircraft, but Daisy tests--to cite one concrete example--have added information on tolerance to the g-forces involved in propelling the ejection seat itself (or other escape device) out of the aircraft. To clear the high-flying tail of modern jet planes a powerful thrust is needed, and therefore both Air Force and aircraft industry representatives have been interested to learn that human volunteers on the Daisy Track have sustained slightly over thirty g's in a position for upward ejection (g-forces parallel to the spine) with no lasting ill effects. It had formerly been thought that anything above twenty-four g's in this position threatened spinal injury, but designers now appear to have a little more leeway. The Daisy Track has also been used to explore g-tolerances in the special position assumed for riding the experimental Convair "B" ejection seat which is discussed below. And it has been used in certain cases to test new harness designs and other specific items of equipment, both for crash restraint and for actual escape from aircraft.[50]

A somewhat different type of research, though still related to escape from aircraft, was conducted by Colonel Stapp in April 1957 amid the dunes of White Sands National Monument, which is wholly surrounded by the Holloman-White Sands Proving Ground integrated test range. The aim was to explore the possibility of remaining fastened in an ejection seat throughout parachute descent. For this purpose a human subject would take his place in an ejection seat, which in turn was attached to a small plastic balloon; he then rose up in the air a short distance and came down with the balloon itself taking the place of a parachute. Impact velocities gradually increased until they began to approach standard parachute-landing speeds. Volunteer participants in these tests reported some discomfort, but it was agreed that the procedure was well worth exploring further.[51]

In addition to the research efforts of its own Aeromedical

Field Laboratory in the area of escape from aircraft, the Air Force Missile Development Center has collaborated in related efforts by the Aero Medical Laboratory at Wright Field. One example is the "manned balloon flight" program that was made a task of Wright Air Development Center's Project 7218, Biophysics of Escape (now replaced by Project 7222: Biophysics of Space Flight), and is often referred to by the short title High-Dive. This program actually dates back to the period when Colonel Stapp was previously assigned to Wright Field, before coming to Holloman, and it was then regarded as a "first step in the development of a floating laboratory for a variety of upper atmosphere studies."[52] However, a more immediate objective was to have human subjects stage experimental parachute jumps from balloon gondolas at altitudes ranging up to approximately 100,000 feet, and this objective was of obvious importance for aircraft escape procedures.

Colonel Stapp not only helped in the preliminary planning for this program while he was at Wright Field but continued to follow its development with interest after his arrival at Holloman. Other officers of the Aeromedical Field Laboratory were also interested, lending their cooperation when needed. The chief concrete support rendered at Holloman, however, came from the local Balloon Branch, which had the task of conducting balloon flights for the Wright Field project. The first launch



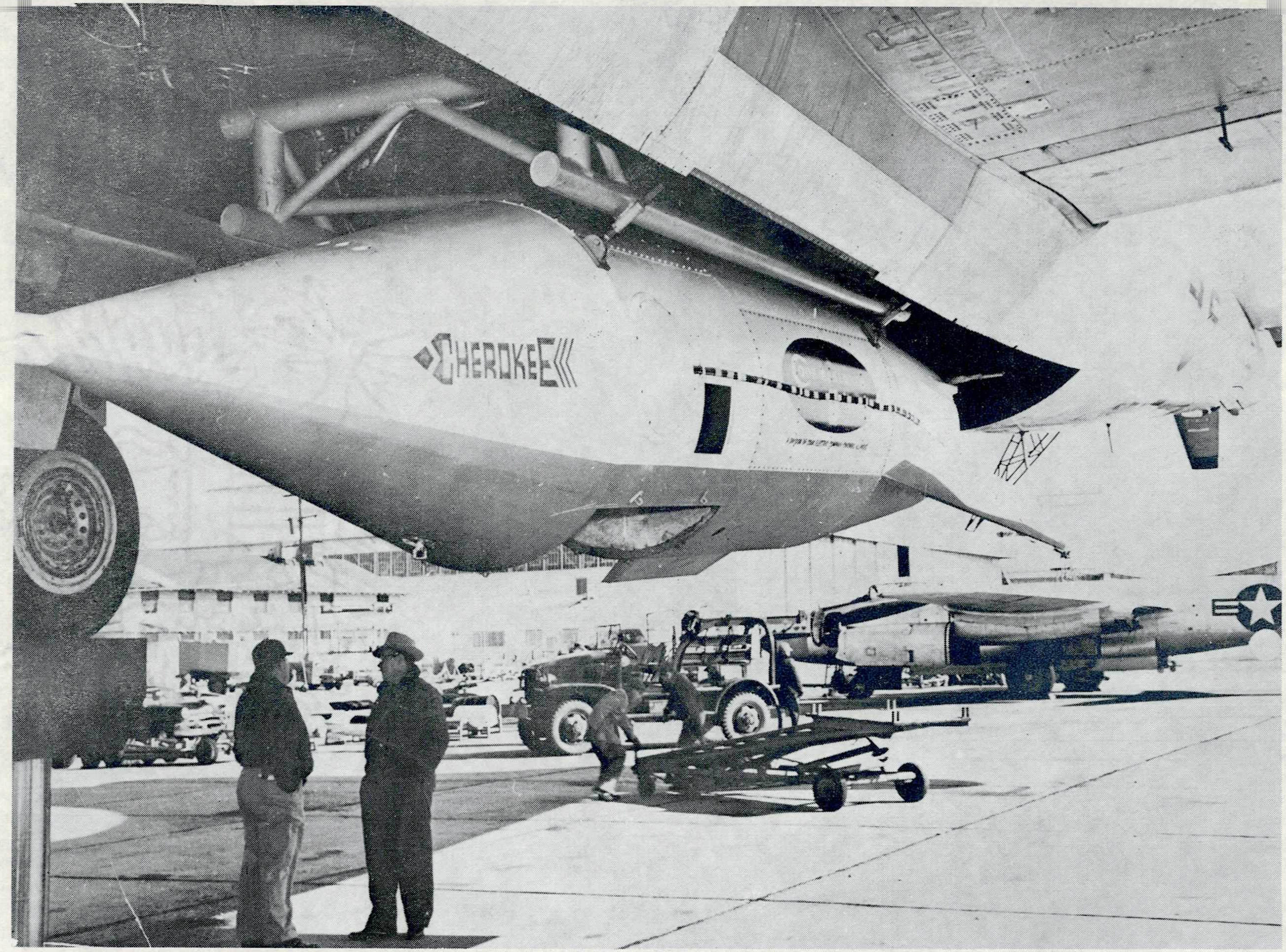
Project High-Dive Dummy Launch

attempt, on 1 May 1953, was unsuccessful, but launchings continued intermittently thereafter. Flights were made to test balloon performance, parachute equipment, and gondola systems; and anthropomorphic dummies took practice jumps for various purposes, accumulating data on free fall or exploring the characteristics of stabilizing parachutes. A few launches were made in the fall of 1955 on behalf of Twentieth Century Fox, which included a Hollywood version of this project in the same motion picture, "Threshold of Space," that featured Colonel Stapp's sled rides.

Project High-Dive also encountered numerous delays, however, and the proposed manned balloon flights have not yet taken place. One of two balloon gondolas developed for the project was appropriately named "[On-Again, Off-Again] Finnegan." Project officers came to Holloman Air Force Base in the fall of 1957 for another series of dummy tests leading up to the actual live bailouts; but before much else was accomplished there was a change of plan in order to provide experimental testing of an escape system developed for the X-15 rocket aircraft. There has also been a change of name, from "High-Dive" to "High-Chair." In effect, the special X-15 ejection seat and allied parachute equipment will be dropped in various tests from a stratosphere balloon, and in the scheduled manned experiment from 97,000 feet the test subject is to ride all the way up in the seat itself rather than in a balloon gondola. What else may finally develop out of the Aero Medical Laboratory's manned balloon program remains a matter of conjecture. Meanwhile, Holloman's own Project Man-High, as described in an earlier monograph, has definitely taken the lead as far as creation of a balloon-borne "floating laboratory" is concerned.[53]

Still another cooperative venture between Holloman and Wright Field with a direct application to the escape problem was Project Whoosh, which aimed to "evaluate escape from a high speed aircraft at approximately Mach 2."[54] The project involved ejection of chimpanzee subjects, from a specially-designed Cherokee missile. The missile was to be taken aloft by a modified B-29 bomber and then accelerated to supersonic speeds before the anesthetized subject, strapped into an open ejection seat, was shot out from the missile's interior. Direction of this activity was assigned principally to the Aero Medical Laboratory at Wright Field, where it became another aspect of Project 7218, Biophysics of Escape, but Colonel Stapp and others at Holloman participated extensively. The Aeromedical Field Laboratory supplied chimpanzees, and Holloman Air Force Base was the site for several of the actual tests.[55]

The first two live ejections took place at Edwards Air Force Base, California, on 26 January and 8 June 1954, at speeds of mach 1.1 and mach 1.5. Then, in 1955, all testing activity

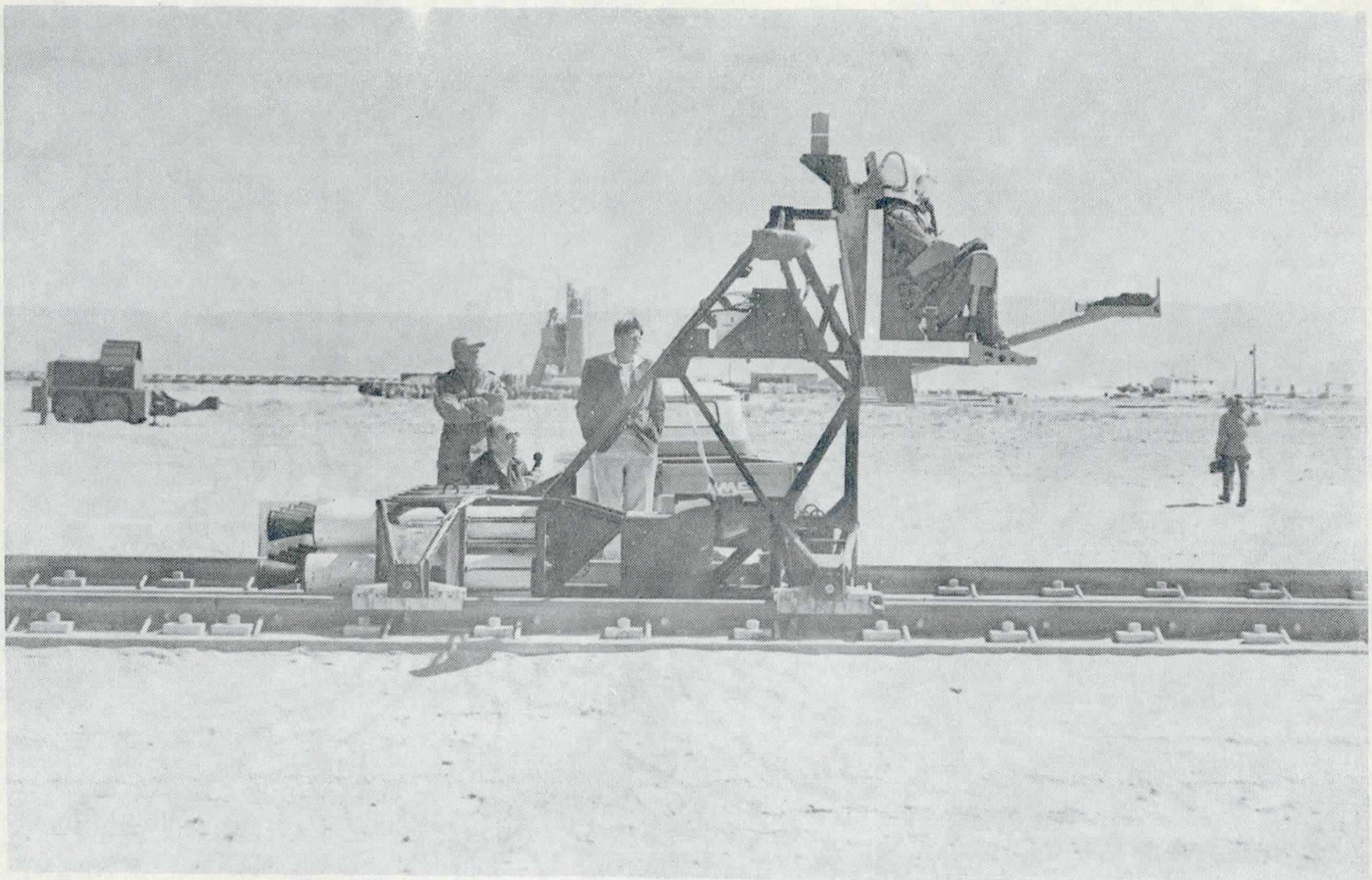


Cherokee Missile Used in Project Whoosh

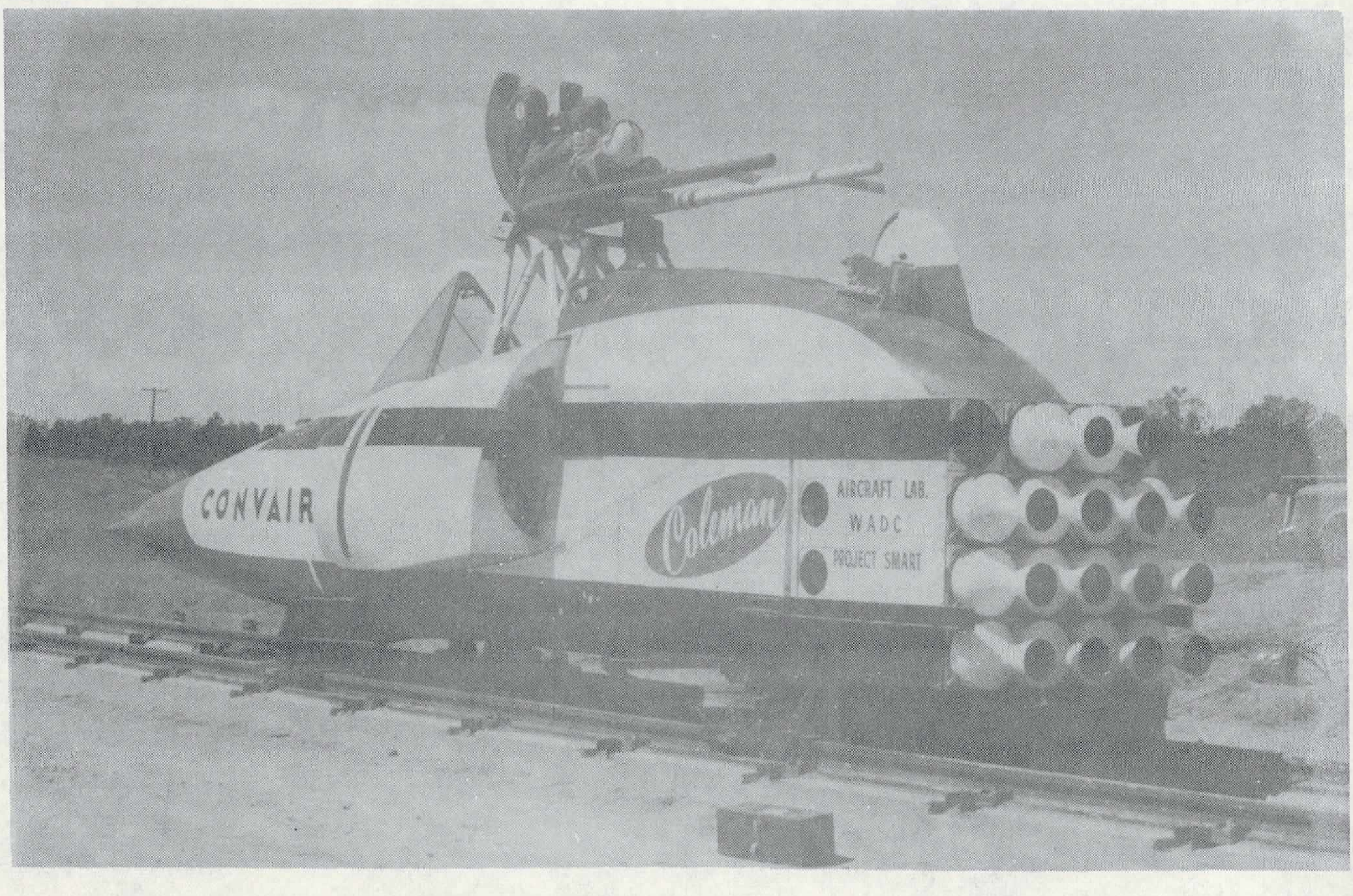
shifted to Holloman, where superior range instrumentation and chimpanzee quarters were available. Two low-speed control studies were made in July, dropping seat and subject from a C-47, without benefit of Cherokee missile. They were followed by two more supersonic ejections on 21 October 1955 at mach 1.5 and 3 April 1956 at mach 1.4, both times bringing the project B-29 (which happened to be the X-1 mother ship) all the way from Edwards at considerable cost in time and overhead. Problems of coordination were multiplied several times over for the last test by confusion and misunderstandings at command headquarters, Wright Field, Holloman, and Edwards as to whether the entire project was or was not being cancelled. It was cancelled beyond any doubt soon after the final Holloman test. Not one of the animals ejected at supersonic speeds had managed to survive, for in each case there were equipment difficulties (with parachute system or ejection seat) that led to death of the subject and overshadowed any possible evidence of injury through supersonic windblast, tumbling, and deceleration. Nevertheless, the project was not a total loss. Even the failures were instructive, and the work performed on Whoosh led directly to further ejection experiments at the Supersonic Military Air Research Track, Hurricane Mesa, Utah.[56]

This last track is an off-base facility of Wright Air Development Center and is especially well suited for tests of escape systems. The track leads straight to the edge of a cliff, and objects fired from a supersonic sled are then lowered by parachute to the canyon floor 1,500 feet below. In a sense, Whoosh operations were simply transferred from mid-air to the track at Hurricane Mesa, with the Aeromedical Field Laboratory still supplying chimpanzee subjects and still taking a direct interest in the proceedings. During the fall of 1956 five chimpanzee subjects were ejected at speeds of about mach one, using a special ejection seat designed for testing rather than for operational use, and three were recovered uninjured. These successful ejections ranged from .95 to 1.15 mach. In March 1957 a chimpomorphic dummy was ejected successfully at mach 1.1, but the next attempt in the series, again using a chimpanzee, was unsuccessful; in fact the sled itself was wrecked.[57]

Meanwhile two members of the aircraft industry, Lockheed and Convair, have been making significant progress with improved ejection seats of unusual design. Each has been specially commissioned to do so, on behalf of the industry as a whole, by the Industry Crew Escape Systems Committee. The Lockheed seat, intended for downward ejection, uses a skip-flow generator somewhat resembling the small bug-deflecting devices often mounted on the hood of automobiles. In Colonel Stapp's words, this "ingeniously surrounds the escapee with an atmospheric capsule, and is an impressive device to extend the range of the



Test of Lockheed Ejection Seat on Holloman Track



Convair "B" Seat Mounted for Track Testing ejection seat." In April 1957 this experimental Lockheed system was tested on the Holloman high-speed track, and it has also been tested (with anthropomorphic dummies) at Hurricane Mesa.[58]

The Convair "B" seat, which is designed for upward ejection, is chiefly distinguished by the telescoping booms that are extended during the ejection process and give the seat a remarkable stability in the air. It is lifted to a horizontal position atop the plane before being fired into the airstream; the pilot then rides feet-first, with knees tucked up and with the rounded bottom of the seat giving added protection. This seat, too, has been track-tested at Hurricane Mesa and at Edwards Air Force Base. It is one of the most promising of all recent escape devices, although naturally the maneuver of raising the seat into position for firing from a crippled aircraft poses some rather complex problems. However, work toward solving these and other problems has been going ahead on several different fronts. One such front is the Aeromedical Field Laboratory, where tests on the Daisy Track have clearly established human tolerance for the predicted g-forces in the exact body position required for riding the Convair seat.[59]

Seats and Capsules: Conflicting Views of Escape

Colonel Stapp warmly welcomed all recent successes in the testing and development of open (seat-type) escape systems, not only because of the intrinsic importance of these events but also because they appeared to support his own views on the relative merits of different escape devices. For Colonel Stapp has been outspoken in the belief that open systems, with technical improvements in the current models of seats and personal equipment, can continue for some time to meet most requirements for escape from high-performance aircraft. In his opinion, both his own research findings as to windblast and deceleration and the latest developments in seat design tend to confirm the usefulness of the ejection seat for supersonic escape. Referring to certain tests of the new Convair seat, he remarked with a measure of rhetorical exaggeration that they were "causing acres of grey hairs among the precocious proponents of the capsule."[60]

Not all those proponents have yet come around to Colonel Stapp's viewpoint (which is generally shared by Captain Mosely also). In fact a large body of thought both inside and outside the Air Force has held for some years that the ejection seat is obsolete for late-model aircraft and that an enclosed capsule system must take its place as quickly as possible. Such a system, it is argued, can offer full protection from windblast; lessen the rate of deceleration through streamlining, though increasing the duration of decelerative forces at the same time;

enhance flying comfort by eliminating requirements for elaborate protective clothing (the "T-shirt concept of flying"); and serve as boat or igloo for any pilot forced to eject over water or on Arctic wastes. Those who take this view, while emphasizing the basic research value of data developed by the Aeromedical Field Laboratory on windblast and deceleration, profess some doubts as to whether the forces tolerated by Colonel Stapp and assorted chimpanzees in high-speed track experiments would necessarily be tolerable to pilots in operational escape situations. T-shirt enthusiasts, in particular, feel that the required amount of protective harnessing would not always be practical. Finally, supporters of the capsule system recognize that the experimental Convair seat incorporates some of the advantages that a capsule offers, but they are not yet wholly convinced it will work, and they insist that while it might somewhat extend the operational capability of the ejection seat, it cannot take the place of a true capsule.[61]

The idea of the capsule system can be traced back roughly as far as the ejection seat itself, to German developments during World War II. The German DFS-228 aircraft had a detachable nose that essentially served as a capsule to bring the pilot down to lower speed and altitude, where he could make his definitive escape by parachute. In the United States, both the Navy and Air Force began active study of capsule systems after the war, and the Bell X-2 rocket plane was equipped with a capsule escape system that was basically designed as far back as 1946. From 1947 to 1952 the Air Force, to avoid duplication of effort, left the major part of United States capsule research to the Navy, while concentrating on seat-ejection improvements, but in 1952 Air Research and Development Command put the Air Force back into full-scale study of capsule escape.[62]

This renewed Air Force interest in capsules bore fruit in July 1956, when the Directorate of Engineering Standards at Wright Air Development Center revised the Handbook of Instructions for Aircraft Designers in such a way that manufacturers were frankly urged to provide capsules rather than ejection seats for aircraft "capable of speeds in excess of 600 Kts. EAS or altitudes in excess of 50,000 feet." The capsule was not made absolutely mandatory, but the wording of the revised Handbook showed a strong preference, which was also the preference of Lieutenant General Thomas S. Power, Commander of Air Research and Development Command, and of certain other high officers both of the Command and of Wright Air Development Center. Moreover, circular letters were dispatched to aircraft companies at the same time calling their attention to the new Handbook and in particular to the indicated preference for capsule escape.[63]

These developments distressed Colonel Stapp. He felt, first of all, that no firm decisions on escape systems should be made until all relevant data had been gathered; and his own studies of supersonic windblast, in particular, were still incomplete. Nor was he overly impressed with the stated advantages of the escape capsule. In answer to the much-discussed comfort factor, he stated that "you can't build a weapon around a rocking chair just because a rocking chair is comfortable,"[64] and he has pointed out that the capsule also has its own disadvantages. These include the larger target area offered by a capsule when used in combat; the difference in cost, with capsules likely to be at least five times more expensive than improved supersonic ejection seats; and a great many technical complications, especially for low-altitude escape, which match or exceed the complications involved in firing the experimental Convair seat.

There are things that can go wrong with the capsule itself after separation from the aircraft, so that it would still be wise to have a pressure suit handy, and ideally (in Colonel Stapp's words) to build in "an escape system for an escape system."[65] In this connection he has observed that the one recorded case in the United States Air Force of attempted capsular escape, in the X-2, was unsuccessful: the pilot managed to detach the capsule from the aircraft but the main capsule parachute failed to open, and the pilot was for some reason unable to abandon the capsule itself before impact.[66] By contrast, supersonic survival with an open escape system has actually taken place. The first man definitely known to have accomplished this feat, test pilot George Smith, suffered severe injuries, but these were due apparently to "high decelerative and rotational forces," sustained in unfavorable body position and with inadequate harnessing. There is no indication that they were due to windblast as such, the one mechanical force against which a capsule, unlike an open seat, can offer complete protection.[67]

The official preference for capsules, as expressed in the <u>Handbook of Instructions for Aircraft Designers</u>, still stands. In practice, however, capsule development is not yet far enough advanced for much to be done about implementing that preference. Thus, for the present, supersonic aircraft--even the X-15--will continue to be produced with open escape systems. Indeed the <u>Handbook</u> revision was no sooner made than the Air Force itself set in motion the program of industry-wide cooperation whereby Lockheed and Convair received primary responsibility for devising improvements in downward and upward ejection seats respectively.[68] Even with these improvements, the performance capability of the open escape system is obviously limited--but so is that of an escape capsule. The difference is one of degree, and the point at issue has been essentially a matter of timing, concerning just how much useful life there still is in open escape systems before they are written off as obsolete.

As a matter of fact, neither the Convair "B" seat nor any escape capsule so far envisaged would be of much use for bailing out of a spaceship midway between Earth and Mars. Nevertheless, much of the research so far accomplished on escape physiology at Holloman and elsewhere has a direct significance for manned space flight. The most obvious example is the applicability of data on g-tolerances acquired from Colonel Stapp's Holloman sled rides to the coming problems of rocket acceleration and deceleration. Those same sled rides, along with other rocket-track experiments on windblast and deceleration, formed the point of departure for the development at Holloman of research efforts on a broad range of biodynamics problems to be treated in a subsequent monograph. And, needless to say, they will long be remembered among the dramatic highlights in the history of the entire Air Force Missile Development Center.

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4. Cf. ARDC Test Directive 5200-H2, Biophysics of Abrupt Deceleration, 25 October 1954.

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7. Address by Col. Stapp at Texas Technological College, 3 October 1955.

8. Lt. Charles E. Wilson, Jr., "The Holloman High Speed Track" (1956); The Holloman Track (AFMDC Technical Report 57-1, September 1957).

9. Ltr., Lt. Col. John Paul Stapp, Chief, Aeromedical Field Laboratory, to Col. A. P. Gagge, Chief, Human Factors Division, Directorate of R & D, Hq., USAF, subj.:

[Holloman Sled Experiments], 12 March 1954; interview, M/Sgt. James F. Ferguson, Aeromedical Field Laboratory, by Dr. David Bushnell, AFMDC Historian, 19 November 1957.

10. History of Holloman Air Development Center, 1 January to 30 June 1954, p. 88.

11. Lt. Col. John P. Stapp, "Effects of Mechanical Force on Living Tissues I. Abrupt Deceleration and Windblast," Journal of Aviation Medicine, Vol. 26, p. 273 (August 1955).

12. Ibid., p. 274.

13. Ibid., p. 275.

14. Stapp, "Effects of Mechanical Force on Living Tissues I," Journal of Aviation Medicine, Vol. 26, p. 277; History of Holloman Air Development Center, 1 January to 30 June 1954, pp. 88-89; Aeromedical Field Laboratory, "Monthly Historical Report," August 1954.

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16. Aeromedical Field Laboratory, "HADC Semi-Annual Progress Report [on Abrupt Deceleration]," July-December 1954; Lt. Col. John P. Stapp, "Human Tolerance to Deceleration," American Journal of Surgery, Vol. 93, p. 739 (April 1957); Stapp, "Human Tolerance Factors in Supersonic Escape," Journal of Aviation Medicine, Vol. 28, p. 79 (February 1957); History of Holloman Air Development Center, 1 July to 31 December 1954, p. 98.

17. Project Abrupt Deceleration, Weekly Test Status Report, 16 September and 26 October 1954, 8 February 1955.

18. Ibid., 26 October 1954.

19. Ibid., 23 November 1954.

20. Stapp, "Effects of Mechanical Force on Living Tissues I," Journal of Aviation Medicine, Vol. 26, pp. 277, 278; Alamogordo Daily News, 28 December 1954. The brick-wall comparison is quoted from a speech by Lt. Gen. Samuel E. Anderson, Cmdr., ARDC (at a meeting of the American Rocket

Society, Dallas, Texas, 19 March 1958).

21. Stapp, "Effects of Mechanical Force on Living Tissues I," Journal of Aviation Medicine, Vol. 26, p. 280.

22. Ibid., p. 281.

23. Project Abrupt Deceleration, Weekly Test Status Report, 14 December 1954.

24. Stapp, "Effects of Mechanical Force on Living Tissues I," Journal of Aviation Medicine, Vol. 26, p. 286.

25. Project Abrupt Deceleration, Weekly Test Status Report, 14 December 1954.

26. Aeromedical Field Laboratory, "HADC Semi-Annual Progress Report [Abrupt Deceleration]," July-December 1954.

27. Stapp, "Effects of Mechanical Force on Living Tissues I," Journal of Aviation Medicine, Vol. 26, pp. 280, 284, 285.

28. Various ltrs., referring to the event, in Col. Stapp's correspondence file, Aeromedical Field Laboratory.

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30. Test Report (Interim Status) on "The Threshold of Space," No. 1, 24 October 1955; Alamogordo Daily News, 4 March 1956.

31. Alamogordo Daily News, 26 August and 25 November 1955, 1 June 1956; Holloman Rocketeer, 8 November 1957. The description of the Cheney Award is quoted from The United States Air Force Dictionary (Air University Press, 1956), p. 112.

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33. Ltr., Col. Stapp to Maj. Rufus R. Hessberg, Jr., Chief, Biophysics Branch, Aero Medical Laboratory, WADC, subj.: [Windblast Tests], 2 January 1957.

34. Alamogordo Daily News, 29 December 1954, 4 January 1955.

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39. "Project 91 Performance Data," 5 July 1957, chart in library of Aeromedical Field Laboratory; Aeromedical Field Laboratory, "Semiannual Progress Report...Project 7850," 1 January-30 June 1955; Test Facilities Division, HADC, "Historical Report," 1 January-31 March 1956; photostats of test data, high-speed track runs of January-March 1957, in files of Biodynamics Branch; "Chimpanzees Pass Space Speed Test," New York Times, 31 January 1958.

    This track extension to 5,000 feet was intended not only to permit higher sled performance but also to enhance the safety of track operations. On some earlier tests the rockets were still burning when the sled entered the water brakes, which was hard on the sled itself and dangerous to the test subject (ltr., Col. Clarence L. Elder, DCS/O, HADC, to Cmdr., ARDC, subj.: "Holloman Air Development Center Annual Progress Report," 31 July 1954).

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46. Sources cited in footnote above; notes by Dr. Bushnell, taken at China Lake 27 June 1957; Center staff briefing by Col. Stapp, 25 July 1957.

47. Cf. Lt. Col. John P. Stapp, "Human Tolerance Factors in Supersonic Escape," Journal of Aviation Medicine, Vol. 28, pp. 77-82 (February 1957); interview, Col. Stapp by Dr. Bushnell, July 1957; interviews, Capt. John D. Mosely, Chief, Biodynamics Branch, Aeromedical Field Laboratory, 19 March and 9 April 1958.

48. Notes at China Lake, 27 June 1957; interview, Col. Stapp by Dr. Bushnell, 7 March 1958.

49. R & D Project Card (DD Form 613), Biodynamics of Space Flight, 19 March 1958, pp. 6, 7; interview, Capt. Mosely by Dr. Bushnell, 9 April 1958.

50. Center staff briefing by Capt. Eli L. Beeding, Task Scientist, Tolerance to Impact Forces, 29 October 1957; interview, Capt. Mosely by Dr. Bushnell, 2 December 1957; Aeromedical Field Laboratory, "Historical Data...1 January through 31 March 1958," p. 12.

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Corporation, Edwards, California, subj.: [Balloon Flights at White Sands National Monument], 18 April 1957.

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65. Lt. Col. John P. Stapp, "Human Tolerance Factors in Supersonic

Escape," Journal of Aviation Medicine, Vol. 28, p. 81 (February 1957). This article is Col. Stapp's contribution to the "Symposium" cited in footnote 61 and gives a general discussion of the relative merits of both capsules and ejection seats.

66. Aviation Week, 1 and 8 October 1956.

67. Lt. Col. John P. Stapp, Escape from Aircraft (n.d.), p. 3.

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INDEX

GLOSSARY

AF	Air Force
AFB	Air Force Base
AFMDC	Air Force Missile Development Center
ARDC	Air Research and Development Command
DCS/O	Deputy Chief of Staff, Operations
Dep.	Deputy
EAS	Equivalent air speed
g	Gravity
HADC	Holloman Air Development Center (redesignated Air Force Missile Development Center as of 1 September 1957)
Hq.	Headquarters
Ind.	Indorsement
Ltr.	Letter
n.d.	No date
p.; pp.	Page; Pages
R & D	Research and Development
RDB	Research and Development Board
Subj.	Subject
USAF	United States Air Force
WADC	Wright Air Development Center, Wright-Patterson Air Force Base, Ohio