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PILOTING PROBLEMS DURING ENTRY

presented by

Flight Research Branch

As airplanes evolve, new problems for the pilot have a way of evolving right along with them. Let's look at this chart which shows the evolution from the current F-104 fighter which looks like an airplane and flies like an airplane, to the rocket-powered X-15 research airplane which looks like an airplane but will fly into regions where it behaves quite differently, and to a typical study vehicle for a manned satellite which is obviously a different breed of cat entirely.

We can pick out about five new problem areas for a human pilot or whatever automatic guidance and control system we want to use just by looking at these pictures and reasoning. What's obviously different here?

1. In the first place these vehicles will have greatly reduced damping compared to the airplane-like shapes. Damping is the tendency for angular motions of the vehicle to subside naturally; you might say, whether you are going to fly steadily like an arrow or tumble like a rock. The long fuselages with tails we are used to have much more tendency to damp angular motions naturally than these more compact objects.

2. Second, their flight will involve large and rapid changes in dynamic air pressure because they change speed and altitude so very rapidly. This is important because so many aerodynamic properties such as the effectiveness of the controls depend on this air pressure and will change rapidly at the same time.

3. Third, for flight outside the atmosphere new types of reaction controls, such as are being discussed elsewhere today, will replace conventional flap-type controls. Shifting one type of control to another as altitude changes will also create piloting problems.

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4. Fourth, there will probably be a good deal of interaction between the controls. For instance when he hauls back on the stick the pilot may not only bring the nose up, which he wants, but he may also slide sideways and roll a little as well, at least until we learn a lot more about control systems for objects like these.

5. Finally, the information needed by the pilot or by the guidance computer will be different and the quality of the presentation of this information to the pilot will be much more vital to the success of the flight. He has to know how he's doing and what to do about it quickly and without confusion.

We've posed quite a list of piloting problems so now let's consider how to work on them. One increasingly important method, the one we've brought you here to see, is to use a flight simulator. A simulator is a device which is set up to imitate an airplane and its controls and responses in order to give the operator on the ground the illusion of actual flight.

It is apparent that you don't have to duplicate the entire airplane or all of its responses for every problem you want to consider, therefore there is a wide variation in the complexity and cost of simulators. The study of how to use simulators properly and of what characteristics it is necessary to build into them is one important facet of our current research. Perhaps the simplest form is a man sitting on a chair in front of a single instrument. The next stage might be the example over here where we have placed the pilot in an exact duplicate of an airplane cockpit. The cockpit is fixed to the floor and does not move, however, all of the instruments the pilot sees are connected to a computer which makes them read just as they would in actual flight. This type of simulator is sometimes

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further improved by enclosing the pilot and cockpit in the spherical projection screen of which you see a portion over there. The projector you see over the windshield is used to project a moving horizon line or a target airplane on the screen and further intensify the illusion for the pilot. The next stage up in complexity is represented by this device, where the pilot is placed in a cockpit that rotates in response to his control motions and thus provides him with real rotational motion cues. The final stage in complexity is represented by the big multimillion-dollar centrifuges such as the one shown on this chart, the centrifuge at the Naval Air Development Center at Johnsville, Pennsylvania. In this machine the pilot is still in a cockpit free to rotate but the cockpit itself is whirled on the end of an arm 50 feet long in order to use centrifugal force to develop tremendous linear accelerations on the pilot. Thus the cockpit is free not only to rotate but to translate or move linearly in one direction. Further development of this type of machine to add more degrees of linear freedom is now in the planning stage.

Why are simulators now becoming so important? There are various technical reasons for their usefulness but the two outstanding factors are safety and economy. The safety aspect is obvious, in the type of flying we are talking about the penalty for equipment failure, pilot error, or wrong choice of test variables is generally catastrophic. The economic argument is equally powerful. Even for existing airplanes and certainly in the future for a manned satellite, research, development, and training flights on the scale we've been used to will simply be out of the question. For instance, 10 or 15 flights in a present-day jet fighter to tailor the longitudinal control exactly to the pilot's wishes

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were reasonable and the cost was commensurate with the result. Ten or fifteen satellite launchings for this purpose seem rather staggering. The same argument, of course, applies to present jet transport development and training operations and the current interest in simulators is certainly not restricted to the space-flight example you're going to see.

In view of the wide choice we have in simulation equipment we must ask ourselves how good the various simulators are for our particular problem. How true are the pilot's reactions? Does our simulator provide him with all the essential cues and signals that he will use in actual flight? How much simulator do we really need? Our next speaker, Mr. _____, will discuss research on these factors.

Here at Ames we have evaluated simple fixed-chair simulators, cockpits free to rotate in pitch only, and this cockpit which is free to move both in pitch and roll. We have compared our results directly with results from flight tests of the airplanes simulated. We have even increased the range of flight-test parameters by simulating our variable-stability airplanes, which in themselves are highly successful as flying simulators. These airplanes are equipped with special devices to move their control surfaces independently of the pilot's control actions and thus make these airplanes behave like other airplanes with completely different characteristics.

This research has already shown us that, as you might expect, the degree of sophistication needed depends strongly upon the specific task we are trying to simulate. For certain flight-control problems this simple fixed-chair simulator here will give the pilot all the "feel" he needs. For instance, our pilots have evaluated quite well on these

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equipment devices, such as thrust reversers, which control their loss in altitude as they come in for a landing. In other problems, such as the control of a longitudinal porpoising tendency, the angular acceleration is a very important cue to the pilot, so it is mandatory to put him in a moving chair such as this and actually reproduce the pitching motion before we get meaningful results. There are other tasks also, such as control of the X-15 airplane in its initial rocket-powered climb where the pilot is subjected to large and rapidly changing linear accelerations and one suspects that the centrifuge type of simulator is necessary. The NACA, Air Force, Navy, and North American Aviation, Inc., are joining in just such research at Johnsville to develop the controls for, train pilots for, and plan flights of the X-15 hypersonic research airplane. Of course, none of the answers are pure black and white. The simplest simulators may still be very useful on almost any problem if the results are interpreted carefully with the correlation principles we have learned in mind. We're now going to demonstrate this simulator to point out some of these factors to you.

For our demonstration we have chosen the problem easiest to show you graphically; the importance of damping to the human pilot.

Let's look at the equipment next. This is the simulator, a cockpit which the pilot controls in pitch (demonstration) and roll (demonstration). This particular unit is capable of high performance. It can be rolled as fast as two complete revolutions per second, fast enough to cause most of us to red out, or to impair our vision momentarily.

This next unit represents the pilot's instrument panel enlarged so you can follow the action. In the center a TV screen represents the

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pilot's attitude gyro. This stationary image represents the simulated vehicle. This horizontal line represents the horizon. It tells the pilot his pitch attitude and bank angle. You see the horizon drop below the airplane as the pilot brings his nose up (demonstration), and you see it tilt as the cab rolls (demonstration). These other instruments show the altitude, the vertical acceleration, the airspeed, the longitudinal acceleration, and the angle of attack. The pilot's control stick is connected to the large electronic analog computer in the room behind. The computer, of course, is the most complex part of the simulator and you will have an opportunity to inspect it as you leave. This computer takes in the pilot's control force or position, the initial flight conditions selected, and the aerodynamic characteristics of the vehicle as determined earlier by other research. From these it continuously computes the information shown here. At the same time it signals the motors to rotate the cab just as the airplane would pitch and roll.

For the final unit we've tilted one of the computer plotting tables up on end and arranged it to show the flight path in terms of the altitude and the range. This little model of the satellite being studied will move along a course representing the flight path. Since there is a lot here to watch, in order to integrate it a little better for you, this model will also rotate to duplicate the pitching of the cab.

We're going to simulate entry of a satellite back into the atmosphere from an altitude of 45 miles and an initial speed of 15,000 miles per hour. While we could show a complete flight, this is the part this particular simulator is set up to study at present since it is the part where the human pilot has the primary control of the vehicle. Remember also that

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our simulator reproduces the rotational motions and accelerations correctly but it does not reproduce the linear accelerations the pilot would have to contend with.

Now there are a number of ways the pilot could attempt to control the vehicle; he could fly at a constant angle of attack (pointing out on instrument panel), he could try to fly a certain planned program of vertical and horizontal acceleration, or he could attempt to match any of a number of theoretical programs of other flight variables. Based on previous studies, we've decided to ask him simply to keep the satellite comfortably level in roll or bank attitude and to fly in at a constant pitch attitude. That is, he will try to keep the displacement of the nose below the horizon, as indicated by this instrument, constant. One reason for having the pilot do this is shown on this chart. By maintaining one of the various pitch attitudes shown, the pilot can select his landing point through a range of about 300 miles. Let's say he could choose to land at Edwards Air Force Base instead of in the Pacific Ocean. But can he hold his attitude constant well enough to do this? Let's find out. In the process we want to show you two things: the importance in this particular task of the cues provided to the pilot by the motion of the simulator; and secondly, the importance of supplementing the craft's natural aerodynamic damping with artificial damping to make the job much easier on the pilot.

The actual demonstration will be presented by Mr. _____.

First of all let's see just how important the motion cues are to the pilot. Do we really need to go to the bother of making the cockpit actually rotate? One way to study this is to see how well the pilot does when we operate the simulator as a fixed cockpit and do not provide him with motion

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cues. He is flying a simulated entry with only the natural low level of damping in both pitch and roll. He is operating only the normal aerodynamic control surfaces. These surfaces are naturally very ineffective with the low dynamic air pressure in the very thin atmosphere up here 50 miles above the earth, but their effectiveness will increase very rapidly as he descends. Notice that he had a good deal of trouble with his lateral balance. Since he is not moving the only way he can perceive a roll disturbance is to wait for the error to build up and show on the instrument. By then, with his low control effectiveness and damping, the best he can do is generally "too little and too late." Well, he lost control completely there. It is obvious he was so busy chasing his lateral balance that he didn't really have time to consider his pitch attitude.

Now let's repeat that run, but this time we will make the cab move so that the roll motions and particularly the small initial roll accelerations are felt immediately by the pilot through the seat of his pants. This time his lateral balancing is instinctive and he does a much better job. Since he can now devote some attention to flying at a constant pitch attitude, let's see how well he's doing. He's keeping that horizon line at a steady vertical position fairly well, but let's not be fooled by our simulation here. Our pilot obviously has a lot less to do and think about than he would in real flight, so let's give him a problem. I'll tell him to change pitch attitude 5° and steady out at the new value. He did that fairly well but the low damping gave him some trouble and permitted oscillations to persist. He has one other pitch-control problem coming up about now. As this vehicle penetrates the denser atmosphere at these speeds it will have a tendency to bounce or skip upwards. This powerful

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disturbance is hard to fight with these controls. You can perceive the skip by noting that the altitude pointer stops descending and seems to hang up or even rise a little. The pilot is trying to keep his pitch attitude constant but he has just gotten used to rather ineffective controls when now the dynamic air pressure rises rapidly as he descends into the atmosphere and the control effectiveness keeps changing on him. In this particular flight this experienced pilot is doing pretty well, but sometimes they do and sometimes they don't. If you consider the added distractions and duties during an actual descent you can see that the pilot needs help. You wouldn't want to put him up in the real thing quite yet.

Now we'll try the entry again, only this time we will attempt to bring the controllability up to a more acceptable level and help the pilot out by artificially increasing the damping. For some time now in conventional fighter airplanes and bombers we have assisted the pilots by adding electronic circuits so that the autopilots take over the job of stabilizing the vehicle against small disturbances. In this way the human pilot is relieved so that he can concentrate on the large control movements necessary to steer the vehicle the way he wants. In effect the vehicle is made to appear to him to have much better damping and we can do the same thing with this satellite. In the simulator it's a simple matter of making some simple adjustments to the analog computer and we're ready to try again. The control proficiency now looks normal and the pilot is able to accomplish his task with a reasonable degree of concentration. Again I will ask him to change his pitch attitude 5°. You can see the benefit of the additional damping. As the descent continues the skip will again pose a problem, but it is much more controllable. You can see the value of the simulator as a research tool for examining critical attitude control problems.

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The entry is continued down to an altitude of 13 miles and a speed of 1,100 miles per hour. These are conditions under which we are operating service aircraft today. Nevertheless, descent from this point on to a complete landing with this future type of vehicle is a fascinating problem in itself. We are now, in fact, developing additional simulator equipment to provide the pilot the cues he needs to judge a high-speed approach and landing or a parachuting descent.

In conclusion, you have seen a flight simulator used for research in an area where actual test flying is going to be quite dangerous, expensive, complicated, and consequently, rather rare. You have seen how, for one particular phase of the problem, lateral balance, it was necessary to complicate our simulator by imposing the true rolling motions on the pilot in order to get meaningful results. You have also seen a typical research use in the investigation of the levels of damping we must provide for adequate control. The simulator will be an equally useful tool for vehicle development and for training flight provided care is taken to give the pilot distractions he will be faced with and all the cues he will have to have to accomplish the particular task he is trying to learn. Thank you!

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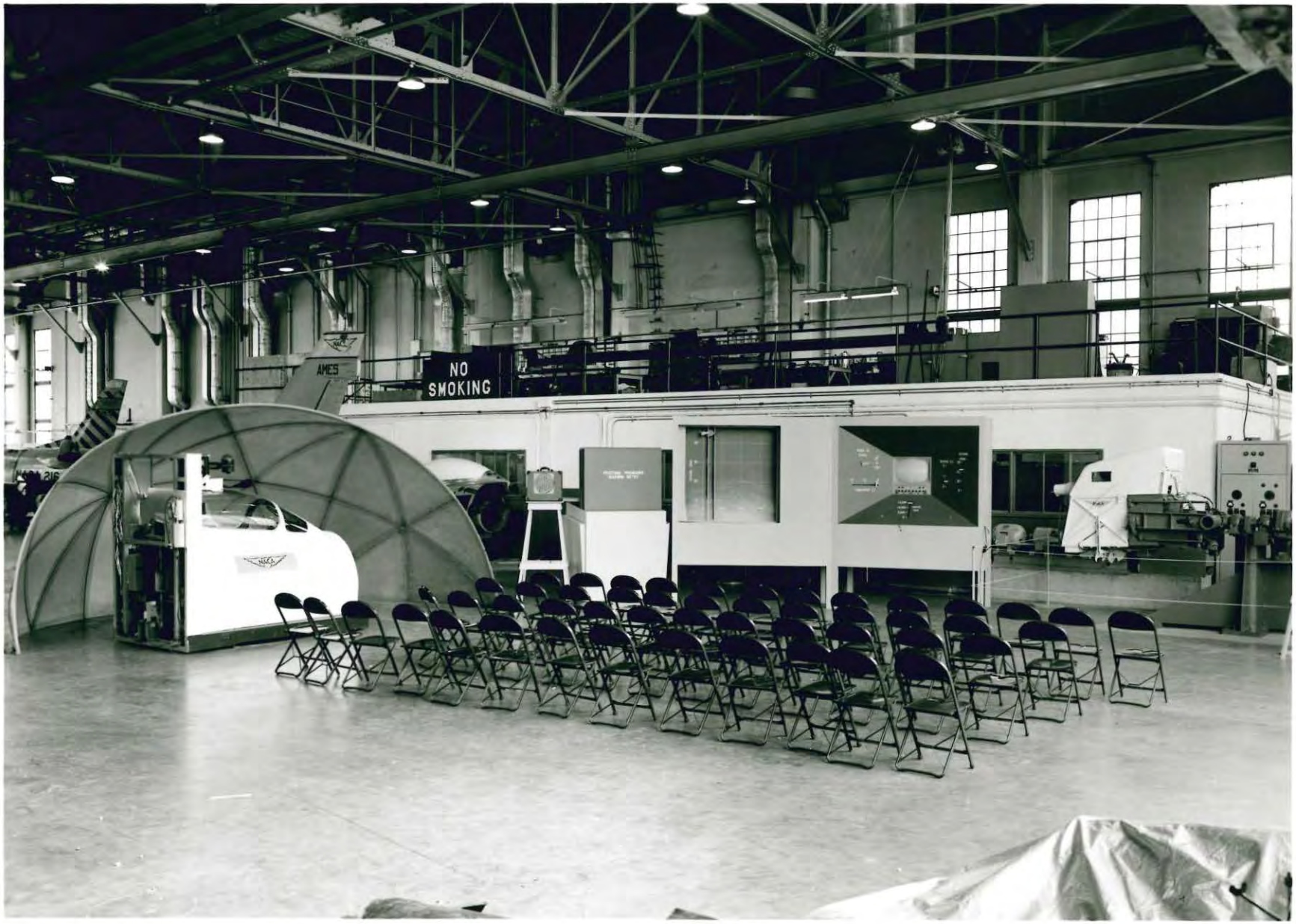

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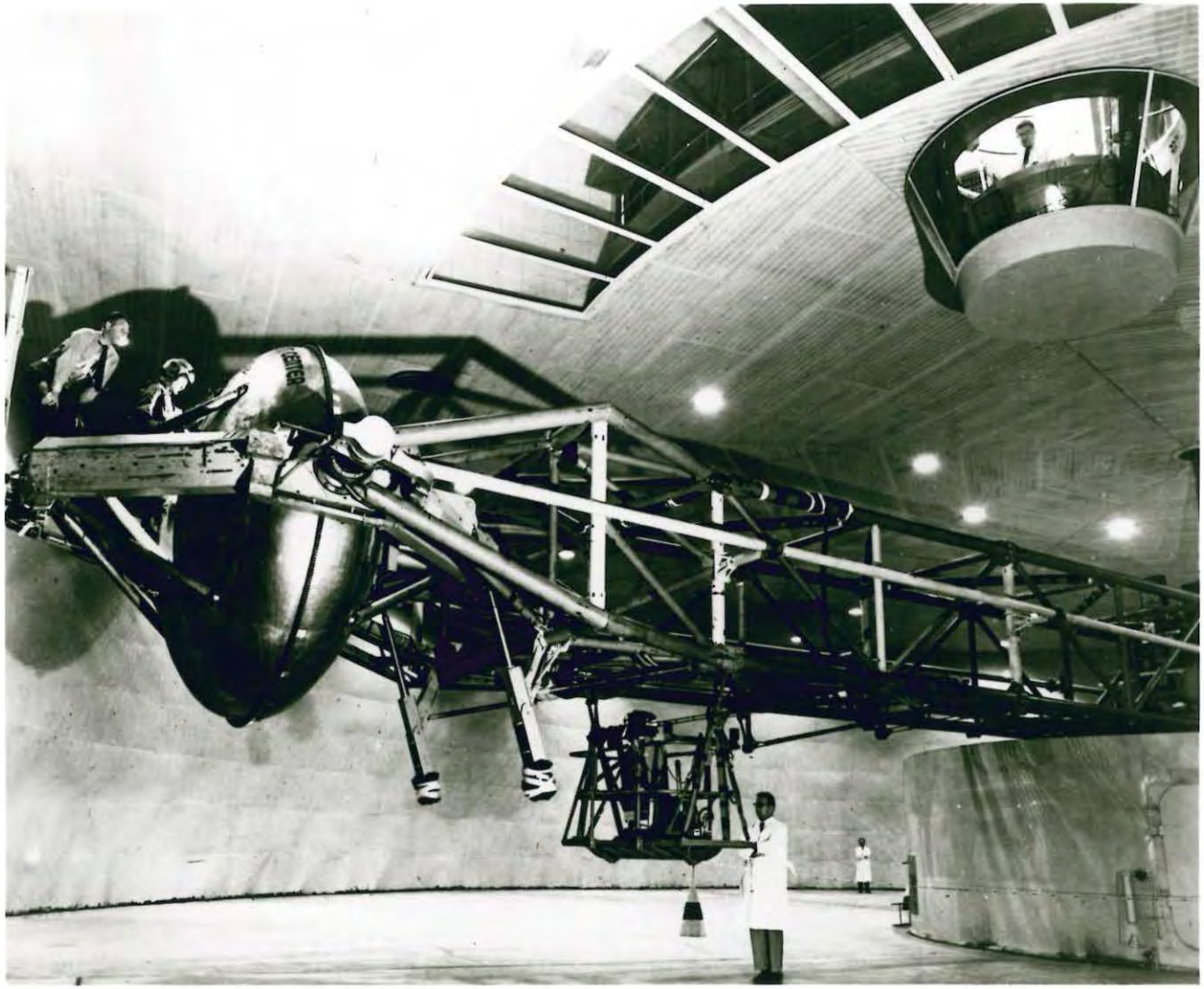

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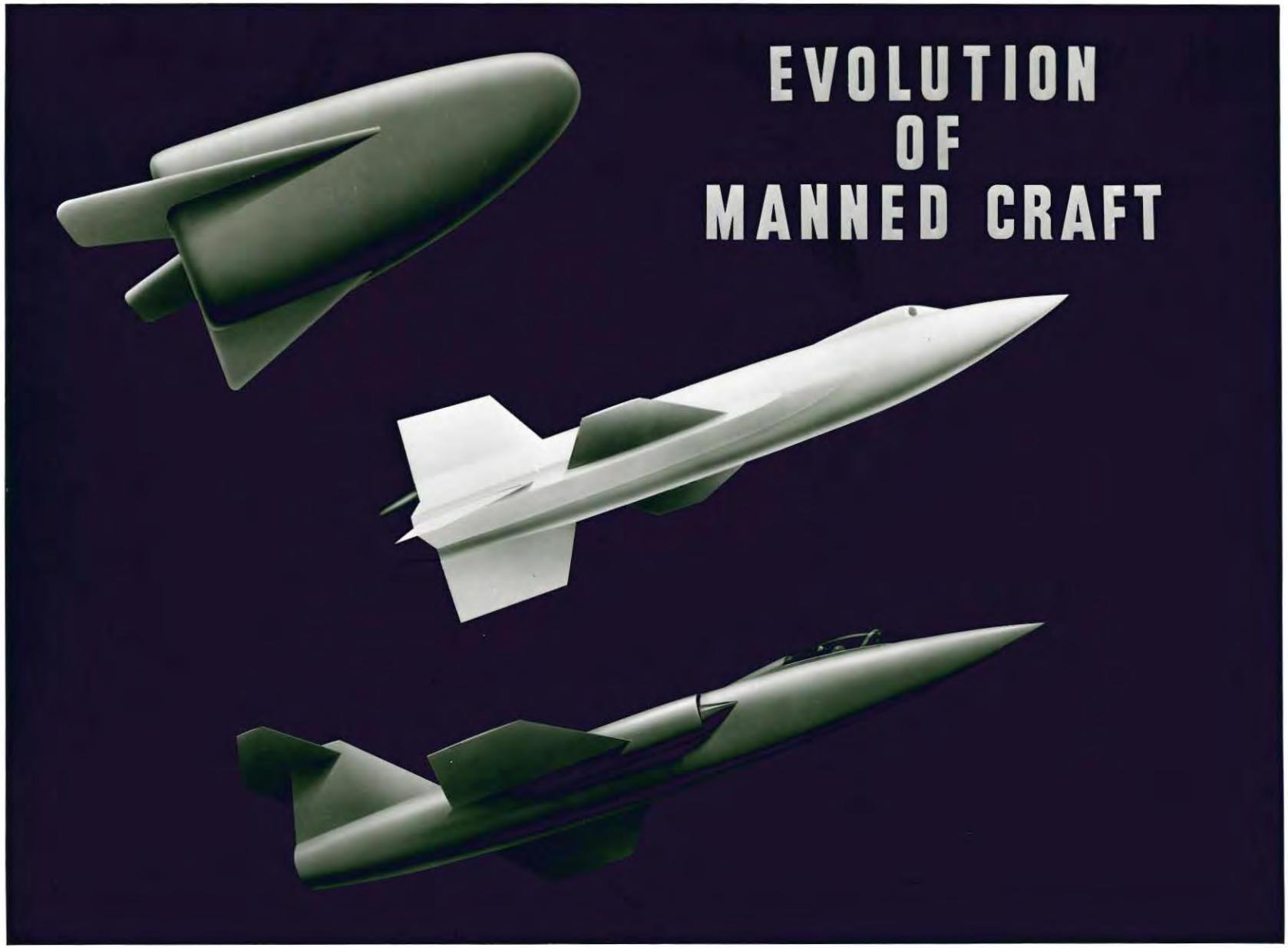

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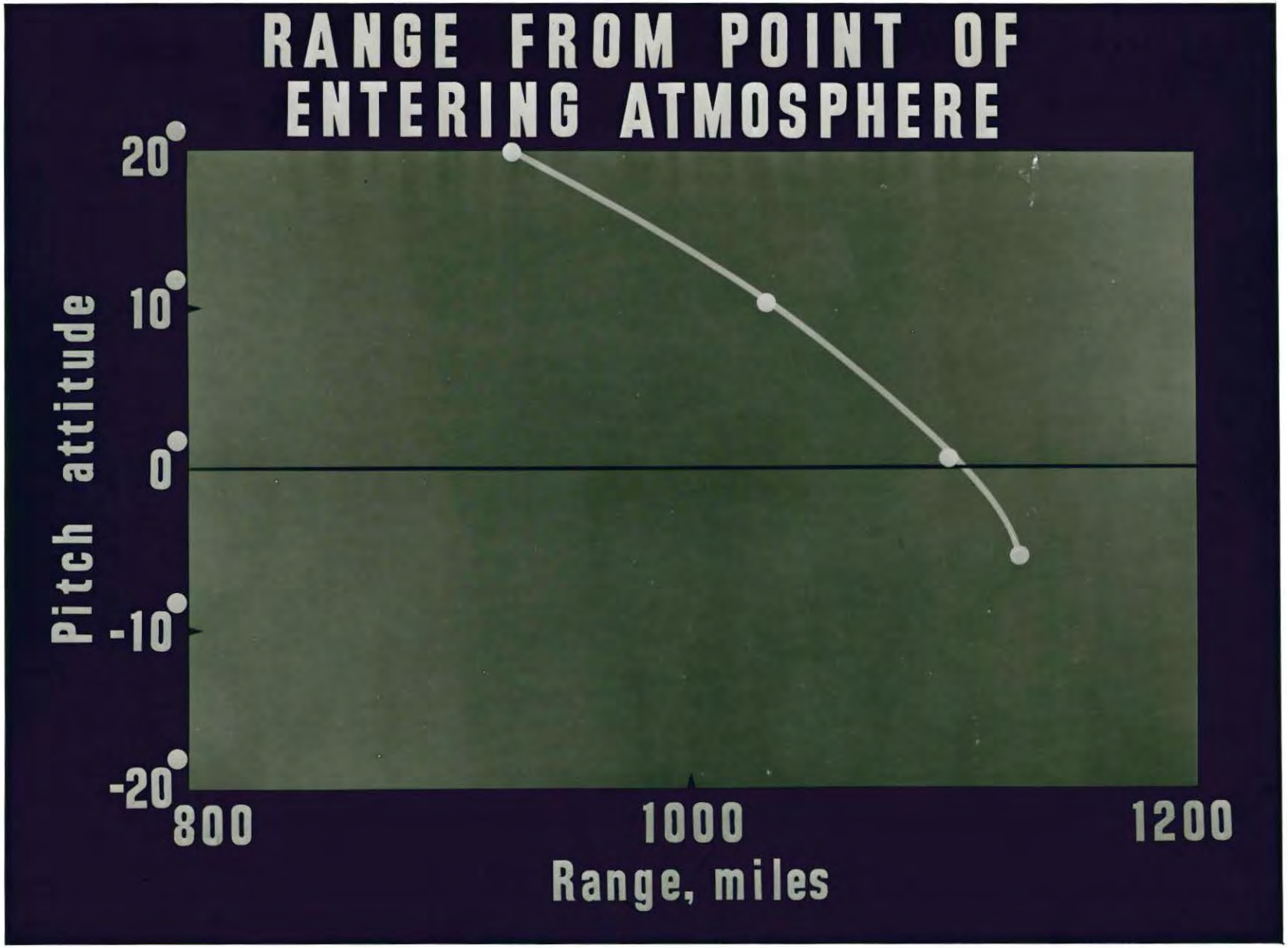

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