"ON TO MACH 12"

Convair HST
With a good physical picture of the phenomena involved, he can often get some quantitative data (even if empirical) and predict some results, using the simplest mathematics that fit the case.

In new fields or difficult areas, where basic data are not available or cannot be calculated, key experiments are required to prove feasibility. Many times this can be done on a critical component that represents the unknown part. Some engineers rely only on calculation, others only on experiment. However, both techniques can usually be employed, and neither should ever be overlooked.

Economic evaluation involves determining the ultimate economic value, which usually can be measured by the total additional income or value that idea will generate. The probable net gain can be compared with the cost of development, including further verification, tooling, and new facilities. With a little help from accounting and manufacturing people, engineers are capable of making such evaluations. Usually there are numerous alternate constructions, and the engineer must strive to find the best economic solution.

Convictions

With many engineers, a major block to reaching a conclusion regarding the worth of an idea and taking action is the desire to be absolutely certain before proceeding. (This search for certainty is sometimes used as an excuse for procrastination.) However, in many technical evaluations, as in most business decisions, there is no such thing as absolute certainty. Therefore, one must rely on a conviction of adequate probability of success.

To determine adequate probability of success for a project or idea, the engineer must consider all key elements necessary for success and all alternate solutions to the problems posed. Generally, he then arrives at a probability-of-success figure by judgment.

Another block to conviction is simply the fear of failure, often based on previous unfortunate experiences. However, if one thinks about a past failure objectively, the reason for failure can usually be determined, either in the idea itself or in the way it was presented. Thus, to gain confidence, the engineer should resolve to evaluate his ideas more fully and to communicate them better. For further motivation, he should contemplate and savor any past successes.

A less obvious block to conviction is the “they complex,” the tendency to believe that someone else should make the decision.

If the engineer recognizes the need around him and takes a positive, confident approach to his problems, he will produce worthwhile ideas. If he uses good judgment in evaluating the ideas and reaches some convictions, he can then take action. This is exerting leadership.

Dealing with Others

Implementing an idea eventually requires the cooperation of others, because very little in engineering can be completed alone. Thus, a major requirement of leadership is the ability to gain the confidence and cooperation of others.

The leader usually is interested in others and recognizes their abilities and worth. People always respond favorably to the person who shows interest in them. But any action involving others must also be carried out with sincerity.

Also, strong leadership requires that we inspire others by appealing to their strongest motivations, and this requires an understanding of their basic motivations. The seminars on creative engineering provided some helpful insights here. Some of the most creative engineers were obviously highly motivated and, therefore, were asked what had driven them to come up with ideas. All agreed that it was a desire for recognition. Some wanted recognition from management, usually higher than their immediate supervisors. Others wanted the recognition of some technical leader they respected, and a few wanted recognition from their peers.

Selling Ideas

Another specific problem in dealing with others is that of selling ideas. Engineers sometimes adopt the attitude that ideas and facts should sell themselves—but experience has proved that the way an idea is presented makes a great deal of difference. The seller must talk the other fellow’s language, choosing both words and concepts the listener can understand and needs to understand. To avoid confusion and a negative reaction, many details of how the problem was solved should be omitted. These details are usually of real interest only to the originator of the idea.

Another good practice is to watch for the other person’s reaction and use it as feedback to control output of words in presenting the idea. This requires watching for the other person’s response and listening when he tries to inject something into the conversation.

A great deal can be learned from a good salesman’s pitch. He knows that his prospect must be in the right mood and must not be worrying or thinking about something else. Next, the salesman gets the listener’s attention on the subject, usually with the most positive statement that can be made of the potential gain to the listener. Then he presents the essential facts, remembering that the things that will move the listener most are those that affect him directly. It even helps to dramatize things a bit and appeal to the imagination, so long as it is not overdone.

Finally, the salesman’s rule: “Ask for the order.” In other words, if the other person hasn’t jumped to the conclusion desired when you think you have sold your idea, ask him if he agrees that certain action should be taken. Leave with an understanding of what the next step should be and who is to take it.

Through any such presentation, don’t be impatient. If an idea is new, it may take the other man as long to grasp its significance as it did for you to originate it.
21st century airliners? Two final configurations, developed by Convair Div., General Dynamics Corp., are among the most advanced hypersonic transport designs prepared to date. Both evolve from aircraft operative today: delta-wing vehicle (top) is relatively straightforward; blended body/double-delta (bottom) is similar to the Lockheed SST design and is based on the Lockheed/Air Force YF-12A interceptor. Like most HST designs contemplated now, these would be powered during cruise with hydrogen or methane fueled scramjet engines utilizing supersonic combustion. They probably would be designed for one of two cruise speeds: Mach 8 or Mach 12.
The year: 1990. A giant transport leaves New York's Kennedy International Airport bound for Tokyo, Japan. Its huge size is impressive, but grossly misleading in terms of passenger capacity. Only 200 people are seated in its quiet cabin, although the craft's fuselage is some 50 ft longer than that of the mammoth 600-800 passenger "jumbo jets" parked nearby. Traveling at nearly 5,000 mph, the hypersonic transport will arrive in Japan 2 ½ hr after takeoff.

Blue sky? Perhaps. But NASA and most aerospace firms today are taking a hard look at the post-SST era, the years 1985 to 2000. A number of feasibility studies already have been made in materials, structures, fuel, and propulsion—and the SST has yet to fly.

Engine Will Fly This Year

Whether or not the scene above ever happens is not a problem in aerodynamics or materials. The current high price of liquid hydrogen (30c per lb, or 8c per seat mile) would be the major obstacle right now if the airlines or government suddenly called for development of an HST. "We would like to see the cost of liquid hydrogen reduced to 5c per lb," says NASA research scientist Richard A. Petersen. Cost of JP fuel burned by present jet transports and which is suitable for SST propulsion is 1.7c per lb.

Other problems are almost as pressing, however. In fact, there is controversy now over the optimum HST cruise speed—a rather basic design parameter. Researchers generally agree that it must be Mach 6 or 12. In-between speeds are undesirable, for a variety of reasons.

E. W. Johnston, chief of research systems and head of hypersonic technology at Los Angeles Div., North American Aviation Inc., points out that hypersonic systems naturally fall into two general categories:

1. Mach 6-8 design cruise speed; liquid hydrogen or methane fuel; multiple-mode propulsion using subsonic-combustion ramjets; cruise altitude of 80,000 to 100,000 ft.

2. Mach 10-14 cruise speed; liquid hydrogen fuel; multiple-mode propulsion with supersonic-combustion ramjet (scramjet) at design speed; cruise altitude of 110,000 to 140,000 ft.

In late 1969, NASA, AiResearch, and North American will mount a hypersonic research engine on the No. 2 X-15. The scramjet engine is being built under a $15-million contract by AiResearch Div., Garrett Corp., Los Angeles. With a weight limitation of 800 lb for mounting beneath the aft fuselage of the X-15, the scramjet will be fueled with liquid hydrogen and operate at flight speeds between Mach 3 and 8 (2,000-5,000 mph). Air Force has already flown a Marquardt Corp. scramjet in its low altitude supersonic vehicle (LASV) development program.
Room for Fuel and a Few Passengers

Little room for payload is available on the HST—liquid-hydrogen fuel tanks fill most of the fuselage. Configurations, right, are fairly representative of HST designs based on current technology extended to 1980.


North American also expects to test a wing panel (removable section) on the X-15 A-2. An identical section will be studied in Langley Field's 8-ft, high-temperature wind tunnel. Then, NASA plans to modify the number 3 ship to a delta-wing configuration and add new tanks for additional fuel capacity.

Convair Study

One of the most definitive feasibility studies yet made of the hypersonic transport was completed recently in a nine-month, $200,000 NASA study by Convair Div., General Dynamics Corp., San Diego, Calif.

Ground rules for this study included:

- An airbreathing commercial transport, operational in the year 1985 to the year 2000.
- Cruise in the Mach area of 3-12, with a sonic boom limitation of 2 psf during climb and 1.5 psf during cruise.
- Takeoff speed, 160 kt; landing, 130 kt.
- Range: Choice of a design range for the hyper-

Insatiable Appetite for H₂

Flying only 100 missions per day, commercial hypersonic aircraft would consume 10,000 tons of liquid hydrogen every 24 hr. To produce liquid hydrogen for 1,000 daily flights would, by present methods, require as much natural gas and electric power as the nation now produces in one day.

Why use H₂ for the HST? First, its energy content per unit weight (or heat of combustion) is about 2½ times that of hydrocarbon fuel. This factor accounts for a vast advantage in cruise efficiency. Second, its cooling capability (specific heat) is needed, because regenerative cooling of internal surfaces of the propulsion system is normally required at high speeds.

But hydrogen is fraught with disadvantages. Its liquid density—4 lb/cu ft, or about one-tenth that of conventional fuel—makes storage volume a tough airframe problem. Its boiling point of —423 F means that it must be carried in cryogenic tanks, which add further to the storage and volume problem.

Hydrogen also is responsible for some monumental structural problems. As explained by Raymond Bisplinghoff, NASA's Associate Administrator for Advanced Research and Technology: "Use of liquid hydrogen sets the lower limit of structural temperature at —423 F. The aerodynamic advantage of sharp leading edges, with stagnation temperatures of 3,000-4,000 F, makes the problem of cooling difficult. This large temperature range also indicates the many material and structural problems to be expected."

Tankage, for example, will present aircraft designers with a lasting challenge. As fuel is burned and tanks begin to warm up, fantastic temperature differentials will occur: as much as 1,000 F between the cold temperature of the liquid hydrogen, and an empty tank by end of cruise period. Tanks will tend to deflect and bow as much as 18 in. Overall result: a 10% weight
sonic transport depends on projected traffic routes. Convair’s study shows that a range of 5,000 nautical miles is a good compromise between takeoff weight, economics, sonic boom, and passenger traffic. About 80% of current international passengers want to travel between places that are 3,000 and 5,000 nautical miles apart. Practically none travel 6,000 to 9,000 nautical miles (some 10% travel the 9,000-mile route from the U.S. and Europe to Australia). A design range of 5,000 nautical miles will, therefore, carry 80% of long-distance, international passenger traffic nonstop. The remaining 20% would have to stop enroute for refueling.

Cruise Speed: Convair’s study points out a surprising factor regarding speed: the big jump in time savings will be obtained by flying at Mach 3—the speed of the SST. The 4,000 to 5,000-mile, Los Angeles-to-London trip will be cut from 11 hr on a subsonic jet to 4 hr on a Mach-3 SST. Increasing the cruise speed beyond Mach 3 will result in surprisingly small gains in time savings: travel time for a Mach-6 flight between Los Angeles and London would be 2¼ hr; Mach 12 would take 1¾ hr.

Much of the projected passenger traffic for the time period 1985-2000 is east-west rather than north-south, and the choice of cruise speed is com-
Giant Among Giants

Big in size and cost, Convair’s proposed HST not only is 62 ft longer than the Lockheed/Air Force C-5A (right), it is much more expensive. First-unit cost, in 1966 dollars, is estimated by Convair to be $160 million. Production units might cost $80 million each. This contrasts with estimated price of $25-35 million for an SST and about $3 million for the medium-range Douglas DC-9.

pounded by the local times of arrival and departure. For example, a 4-hr Mach-3, 8 a.m., Los Angeles flight would arrive in Rome at 9 p.m. the same night. So after only a 4-hr day, the traveler retires for the night, waiting until next day to conduct his business! A Mach-6 airplane would arrive in Rome earlier, at 7:30 in the evening; a Mach-12 airplane would arrive at 6:45. Although these higher speeds reduce trip time, they do not provide the traveler with any more meaningful time in Rome. Choice of cruise speed, therefore, will depend on economics and convenience, rather than mere time saving.

Frank E. Jarlett, engineer in charge of the Convair study, says that these route studies, plus many technical factors, point strongly to Mach 6 as being the best cruise speed for the HST. For the relatively short design range of 5,000 nautical miles, Mach-12 scramjet propulsion would be used inefficiently: 2,000 miles would be traveled in acceleration to Mach 12; the remaining 3,000 miles for a gliding descent. A Mach-8 scramjet is more efficient than a Mach-12 system and will result in an airplane weighing only 3/4 as much. However, even the Mach-8 scramjet is 60% heavier and 40% more expensive than a Mach-6 turboramjet-powered vehicle.

Thus, because of the population distribution around the world and the different time zones, Convair’s study suggests that the HST will be a Mach-6 vehicle with a 5,000-nautical-mile range.

Propulsion Problems: In trying to find the best engine concept for Mach-6 cruise, Convair engineers evaluated the many proposed concepts for hypersonic aircraft. “Most of them don’t make sense for a commercial transport,” says Jarlett. Most of the engines that have been studied to date have been compromised too much in the direction of a lightweight accelerator, and not enough for good cruise fuel economy. Convair engineers point out the need for low subsonic fuel consumption for air traffic control in the vicinity of the destination airport, as well as for overwater flight where cabin or engine failure may require the trip to be completed at subsonic speeds.

Noise: Sonic boom clouds the whole issue of HST. Just as it was a strong factor in the selection of Boeing’s swing-wing SST design over the

Mach Terms

In most aerodynamic circles, Mach-5 has been chosen arbitrarily as the threshold between supersonic and hypersonic. Mach 10 is the threshold between hypersonic and hyper-velocity. Even referencing in these terms to Mach numbers can be a little vague, however, when it is remembered that the speed of sound decreases as the temperature decreases.

A 2000-mph vehicle, for example, will be traveling at Mach 2.6 when ambient temperature is about 60 F. In a temperature of -70 F, its Mach meter would read 3.

Mach number is defined mathematically as the ratio of the local velocity, U, to the local speed of sound, a, in the medium in which the vehicle is traveling (M = U/a).

For general discussion of hypersonic vehicles, a speed of 700 mph per Mach number can be assumed (this is roughly the speed of Mach 1 at an altitude of 120,000 ft).
For Daring Passengers and Skilled Pilots

Boost-glide concept is advocated by some researchers as the quickest way to develop an HST. They argue, with some logic, that engine technology for this type of vehicle is already fully developed. A big turbojet-powered booster would carry the small HST to high altitude and speed. The HST would fly by rocket power. Concept resembles that used today in launching the X-15 and other research aircraft. Marquardt Corp. and others have suggested this approach for almost a decade.

Lockheed double delta, so it can make or break the HST concept.

The SST flying at Mach 2.7 at 65,000 ft altitude will produce a sonic boom overpressure of about 1.6 psf. FAA studies indicate that the public will probably not tolerate this, so the SST will be forced to fly subsonically over populated areas. On a typical, part overland Los Angeles-to-London flight, a subsonic jet would take about 11 hr. If the SST is restricted to subsonic flight over the U.S., then the flight plan may be: subsonic to New York, refuel, then supersonic over the Atlantic, for a total trip time of $8\frac{1}{2}$ hr. If overland supersonic flights are allowed, then the total trip time, including a refueling stop, would be 6 hr.

The HST flying at Mach 6 and 100,000 ft altitude gets a big relief because of the high altitude. It will only generate about 1 psf overpressure. Whether the HST makes sense or not depends directly on what value of overpressure is acceptable. If 1 psf is acceptable, then the HST can offer a 2-hr trip from Los Angeles to London vs 6 to $8\frac{1}{2}$ hr for the SST.

If 1-psf overpressure is unacceptable, it is hard to see a case at all for the HST. It will be forced to spend a large portion of its flight time at subsonic speeds where it cannot hope to compete economically with a subsonic jumbo jet.

Mission Profile: Convair engineers, who presumed that the public will learn to live with 1-psf overpressures, examined four HST configurations in detail: 1. Delta wing. 2. Variable-sweep wing, similar to that on the winning SST design submitted by Boeing Co. 3. Blended body/double delta wing (wing blends into the fuselage). 4. Blended body/variable sweep wing.

The blended body/double delta configuration emerged as the most promising of the four. According to Convair, a hypothetical aircraft based on this design would carry 200 passengers in a 320-ft fuselage. It would have a 100-ft wingspan and weigh about 500,000 lb.

In a typical HST mission, the aircraft would take-off and climb to 100,000 ft, reaching Mach 6 in 1,000 seconds. It would cruise at 100,000 ft for 4,000 seconds (about one hour) at Mach 6. It would thus travel about 500 miles during climb, 4,000 miles at Mach 6, and 500 miles during descent. Allowance for loiter time (at Mach 0.9): 1,700 seconds for diversion to alternate and hold. Total mission time: 8,500 seconds, or 2 hours and 20 minutes, including loiter time.

Convair's proposed HST would have a takeoff thrust of 356,000 lb, compared to 240,000 lb for the SST and 41,000 lb for the Convair 880. Noise at takeoff from the airport would be severe unless propulsion researchers come up with dramatic new developments. But sonic boom generated from the HST would be less severe than that predicted for the SST, because of the HST's higher cruise altitude.

Jarrett concurred that cost and production feasibility of large quantities of liquid hydrogen would be among the most critical problems to be solved before the hydrogen-fueled HST is feasible.