Market Dimensional Expansion, Collapse, Costs, and Viability

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Abstract: Most government programs have cost caps and minimum force requirements. Commercial projects usually begin with a budget, sales targets, and specifications. All too often, in both cases, producers and customers give little thought to the changing market structures they face. When it comes to Demand, markets self-organize to form up to four boundaries each, including 1) Upper (price-limited), 2) Outer (saturation-limited), 3) Inner (efficiency-limited), and 4) Lower (margin-limited) Demand Frontiers. When new market segments appear as different product forms with enhanced functionality over existing options, as the new markets grow, the product groupings they replace may contract across one or more Demand Frontiers. This paper examines preparing for these inevitable eventualities in an N-dimensional framework.

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1. Introduction

Standard economic theory works for simple commodities with one primary feature, such as those for iron ore, platinum, silver, or gold. In those cases, simple supply and demand models dating back to the 1800s work well.

We can better describe all other markets with four-dimensional systems, in which a three-dimensional Value Space shares a common price axis with a two-dimensional Demand Plane, forming a 4D system. Since all of them share the price axis, with appropriate dimensional expansion and collapse, it is possible to portray each simultaneously and over time. Expansions and collapses of markets have happened since their dawn. This paper examines their nature in both cases, offering insights into how to deal with market expansion and collapse.

2. What is a 4D System?

We can describe the location of any vessel using latitude and longitude. Current measurements using these metrics often use as many as six places past the decimal point for the degrees. With one degree of latitude taking about 69 miles of arc, we can plot and pinpoint a ship's position within a few inches. That amounts to a 2D coordinate system.

If we wanted to plot a plane's location in flight, we could add elevation to our plotting scheme, revealing a 3D coordinate system.

As we'll discover presently, a 4D market plot takes one 2D system and appends it to an appropriate one in 3D. The trick, such as it is, is that 4D systems exist in market or mathematical realms and do not have direct connections to those we find in physical systems.

The simplest way to start building a 4D market system is to plot its Demand over a fixed period. If, for example, we were to plot the Quantity of business aircraft sold from the beginning of 2009 to the end of 2018 on the horizontal axis and their average prices on the vertical axis, we would have the view we get in Figure 1.

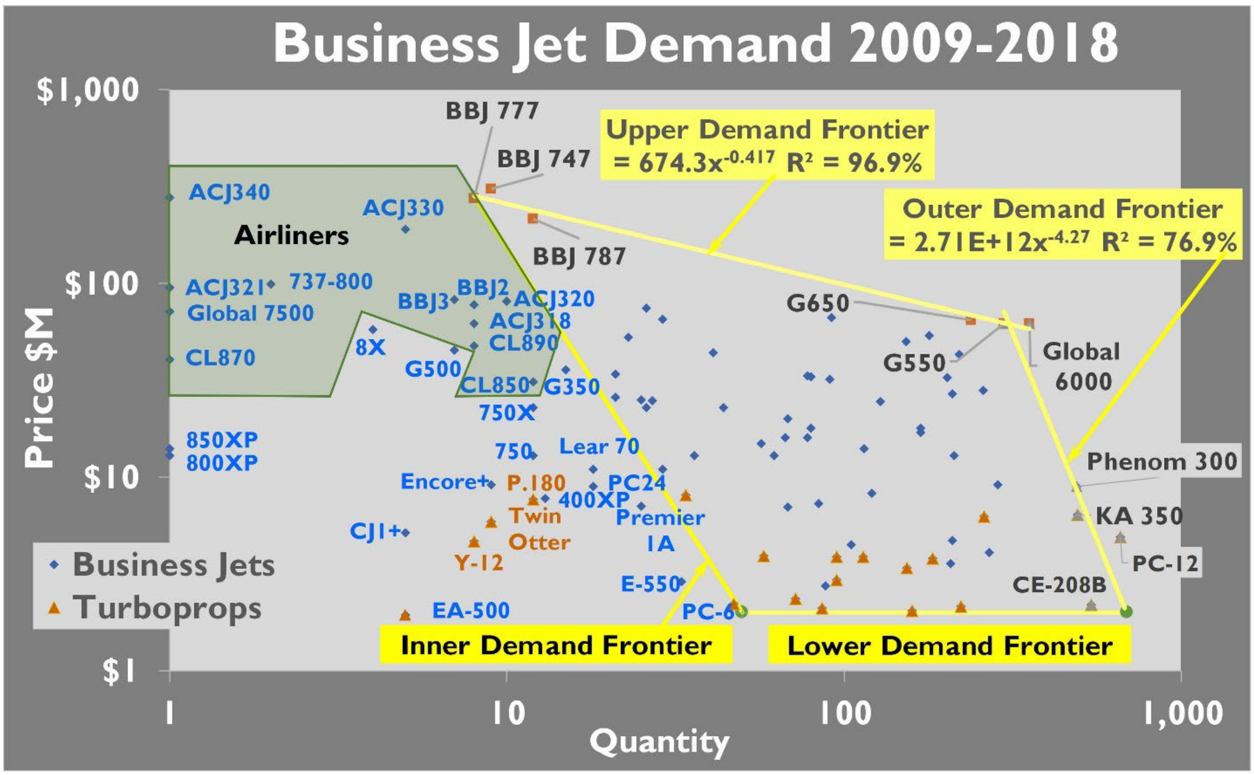

Figure 1 – This Market has Minimum, Upper, Outer, and Lower Demand Frontiers [1]

Figure 1 shows that Business Aircraft Demand is not the simplistic single line drawn in virtually every introductory textbook on economics. Instead, it consists of a series of points, with the quantities of a given model sold shown on the horizontal axis and their average Price on the vertical. It has boundaries. Specifically, it may have up to four distinct limits, known as Demand Frontiers.

The *Upper Demand Frontier* represents the price-limited constraints the market imposes upon itself. It is impractical to try to target sales far beyond the statistical limits of this line, as Aerion found out with its AS2 Supersonic Business Jet. Aiming for 300 units sold in a decade at an average price of $120, they only received 20 firm orders and went bankrupt. [2]

An *Outer Demand Frontier* exposes the threshold at which the market saturates itself with products and represents the quantity limit markets set for themselves. A Price reduction in this market may result in a few more sales, but inevitably, the market cannot absorb more products.

Often, *Lower Demand Frontiers* reveal themselves, as shown in Figure 1, where a lower boundary of $2 million a plane has formed. At such low prices, there is not enough margin between the Price of the plane and its recurring cost. Someone can build an aircraft for less than $2 million in a category with lower standards, as all or most General Aviation planes sell for less than that amount, but such vehicles do not meet the stricter FAA requirements placed upon turboprops and business jets.

Inner Demand Frontiers represent the minimum Quantity needed to keep a production line going, which varies according to Price. Sometimes, this line is highly correlated, as we find studying unmanned reconnaissance platforms in Figure 2. If we collect the quantities sold and prices for Unmanned Air Vehicles (UAVs) and add their military and spy satellite counterparts, we get the view we see in Figure 2.

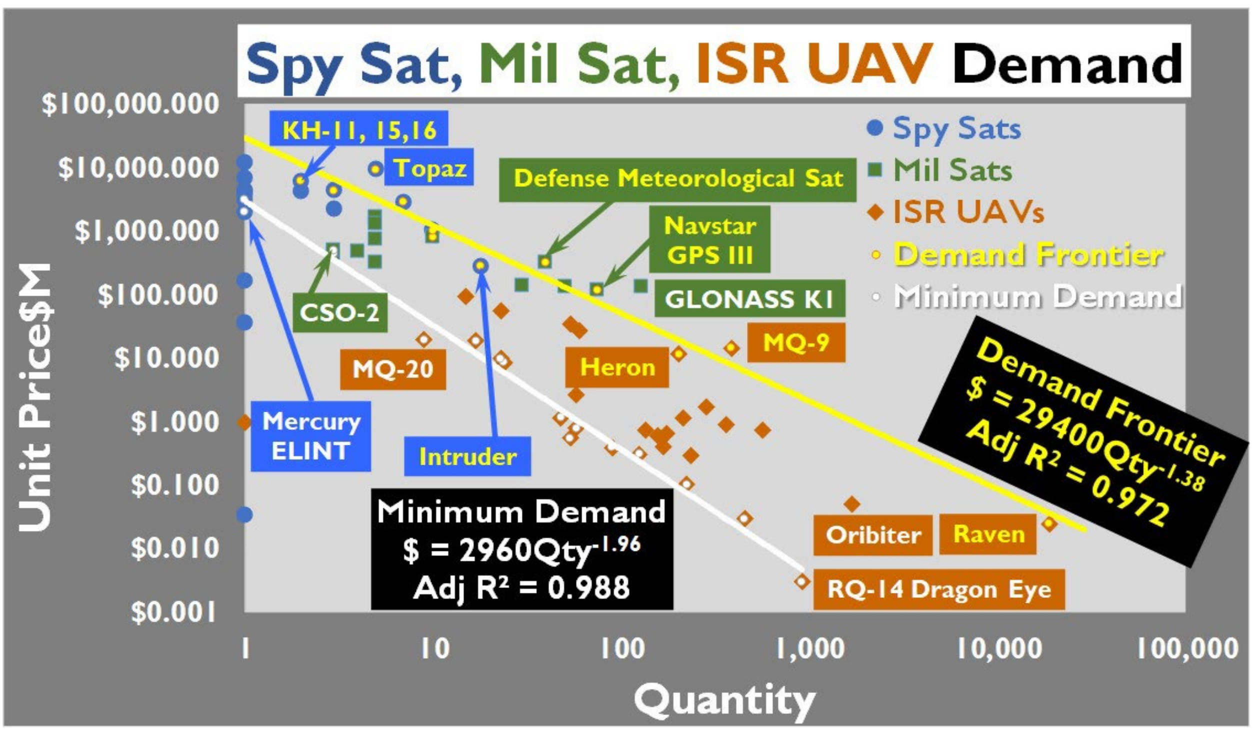

Figure 2 – This Market has highly correlated Minimum and Outer Demand Frontiers [3]

We observe in Figure 2, examining a market created by and solely used for governments, that a sharp Minimum Demand line has formed for these devices. It essentially relates to us that if we are good enough to get past the first unit (and note that a few models were not, and made just one version of the model, and were stopped), we can be assured of making a certain baseline amount we can call *Minimum Demand.* This threshold is a common feature of government markets, as the same limits form in the markets for bombs, missiles, fighters, and bombers.

But, in the commercial world, things are different. Back in Figure 1, that dividing line is fuzzy. In this market, in the shaded area, companies such as Airbus, Boeing, and Bombardier, all of whom produce airliners, can stand relatively low rates for their business jets, as those planes are modifications to units coming off their production lines. Their production lines can continue to make planes as long as Demand exists for the models in question. Models that command fewer sales than this line are more likely to stop production than those past it, as shown in Figure 3.

Model	Status Jan 2024
Gulfstream G500	In production
Falcon 8X	In production
Harbin Y-12	In production
Viking Twin Otter	In production
Avanti P.180	In production
Pilatus PC-24	In production
Cessna CJ1+	Stopped
Pilatus PC-6	Stopped
Eclipse E-550	Stopped
Learjet 70	Stopped
Bombardier CL-850	Stopped
Gulfstream G350	Stopped
Extra EA-500	Stopped
Textron Premier 1A	Stopped
Textron 400XP	Stopped
Textron 750	Stopped
Textron 750X	Stopped
Cessna Encore +	Stopped

Figure 3 – Aircraft models below the *Inner Demand Frontier* are more likely to cease production than those past that line

Some companies, such as Textron, failed to make enough planes to keep their production lines running efficiently and went out of business, taking their four models at the bottom of Figure 3 with them. One of the early market entrants, Learjet, which had been in business for nearly 60 years, fell victim to the same fate. Bombardier, Gulfstream, and Pilatus ceased building the CL-850, G350, and PC-6, respectively, but all had other models that succeeded them. Cessna ceased the Encore+ and CJ1+ and also used replacement models. The Eclipse 550 was an attempt to revive the poorly conceived Eclipse 500, and that program went under with just 33 sales. [3] The Extra EA-500 was an attempt to compete with the thousands of Pilatus PC-12 and the Socata TBM series that the market loved, and it and the company ceased operations after 14 years of production.[4]

The models in production in Figure 3 that were in production were either gearing up to full rate production (as in the case of Viking with its Twin Otter, Pilatus with its PC-24, Gulfstream with the G500, and Harbin with its latest version, the "F," of its Y-12 model) or when faced with thin sales, relied on heavy subsidies from their respective governments (this includes Dassault, with their Falcon 8X, receiving subsidies from the French government, and Avanti, getting money from the Italian authorities). [5], [6]

So, while we've seen how buyers react to the prices offered to them with quantities sold in a couple of markets, we still have not addressed what holds those prices up. This varies from market to market, but generally, we notice that markets like features that generalize to broad categories. While we could choose from features such as endurance, safety, and flexibility for aircraft, primary attributes such as capacity and speed are often dominant. We might guess that we could use some measures of each to predict the sustainable Price of business jets, and we do that in Figure 4, where we characterize capacity as Cabin Volume in cubic feet (shortened to Cab Vol) and portray our speed component as Maximum Cruise Speed in Miles Per Hour (or Max MPH). Both features combine to produce points in 3D space that reflect speed and capacity on the horizontal axes and Price on the vertical axis.

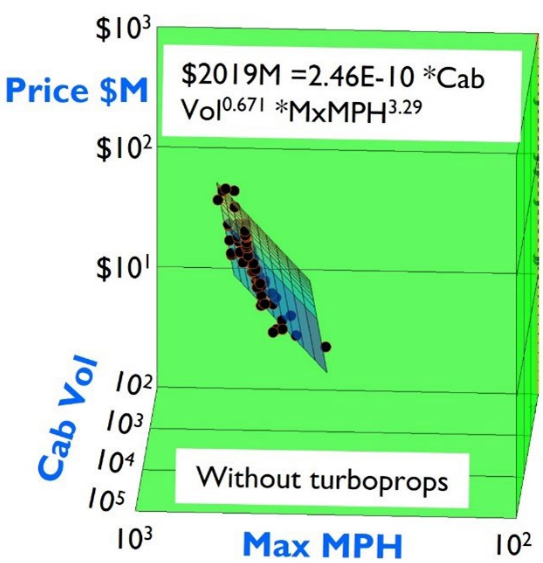

Figure 4 – Business Aircraft Value comes from Speed and Cabin Volume

While the data in Figure 4 is very well correlated, that fact is not as important to us now as seeing what Figure 4 has in common with Figure 1. Sure, both figures address the business aircraft market over the same time frame, but something else should catch our eye. That is, both illustrations share the Price axis. This means that they abut one another in a 4D arrangement consisting of ordered quads, which here form as (Max MPH, Cabin Vol, Price, Quantity) and which generalizes to (Valued Feature 1, Valued Feature 2, Price, Quantity). We see how this complete arrangement looks in Figure 5.

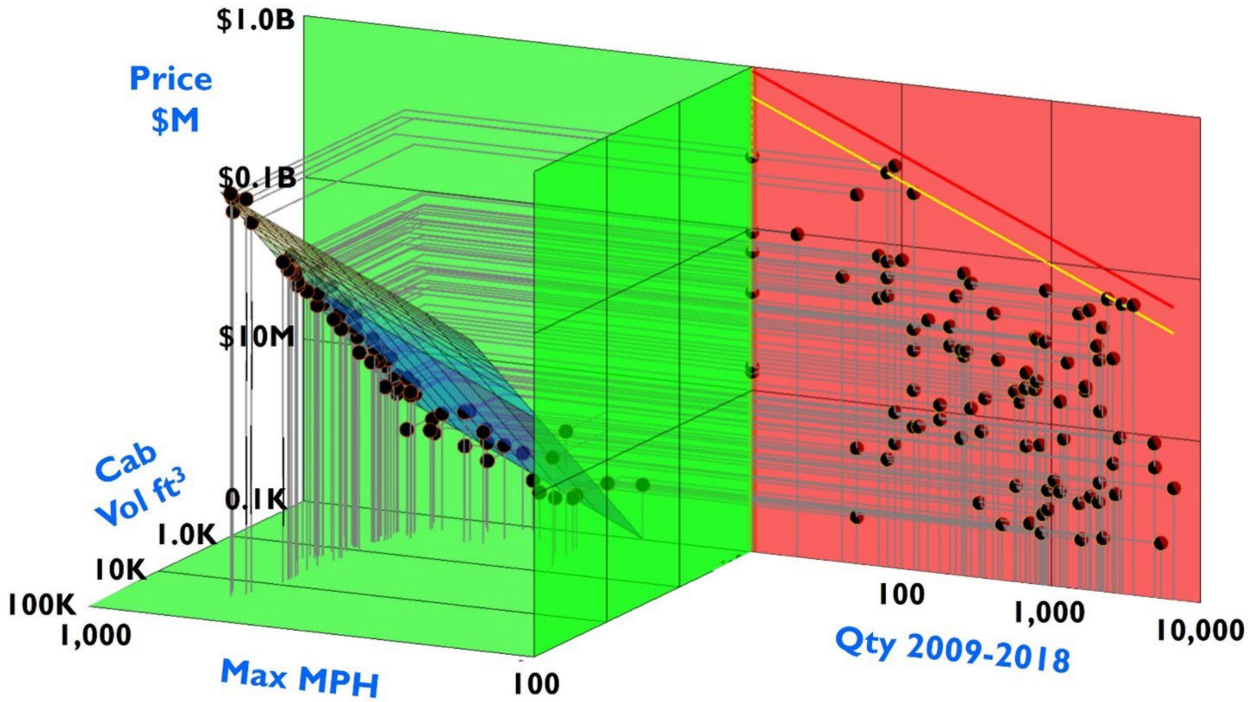

Figure 5 – A 4D view of the business aircraft market, where all points in the left-hand Value Space connect to their right-hand counterparts on the Demand Plane as point-lines

Given that we have found one market we can describe in four dimensions, we might reasonably wonder if we could find more. With just a bit of research, we discover we can.

3. What is a 7D System?

We can create a 7D system if we start with one 4D system and add another. We can do this because all 4D market systems share the price axis. So, understanding that lets us draw the 4D market for the turbofan engines that go into the business jets we just studied, as shown in Figure 6.

There, we find that the Value of turbofan engines goes up with added thrust but down with increased Specific Fuel Consumption (Specific Fuel Consumption, or SFC, is akin to the miles per gallon of range we measure in cars with internal combustion engines). Demand in Figure 6 has a flatter slope for its Upper Demand Frontier, and no discernible Outer Demand Frontier appears. Observe that we have also changed the scaling from the log form we used for business jets to linear versions for all axes.

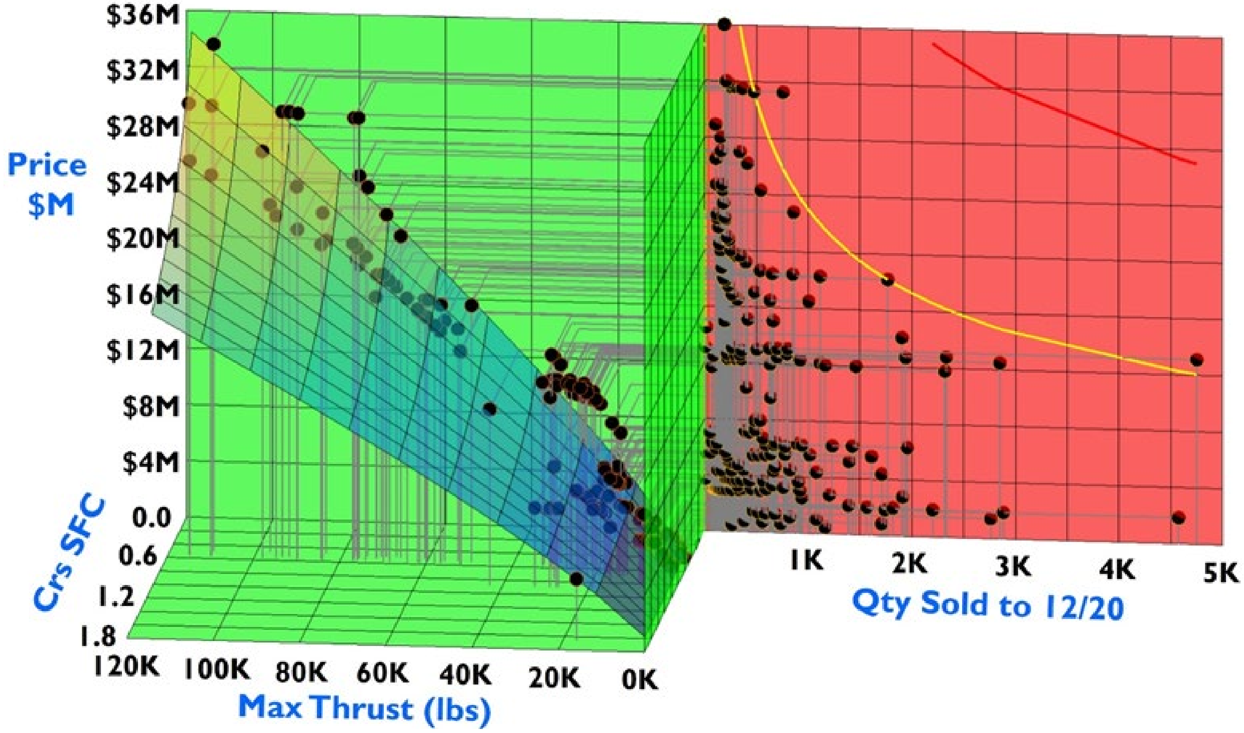

Figure 6 – Here's a 4D view of the turbofan engine market. Value in engines goes up for added thrust and down for increased SFC. As with Business Jets, all points in the left-hand Value Space connect to their counterparts on the Demand Plane as point lines.

Figure 6 shows us that 4D coordinate systems are not limited to business aircraft, as we can apply the same techniques we used for aircraft to their engines. Now, if we were to change the scaling in Figure 6 and match it to what we used for Figure 5 and then recognize that both planes and engines share the price axis, we could get the 7D view we see in Figure 7.

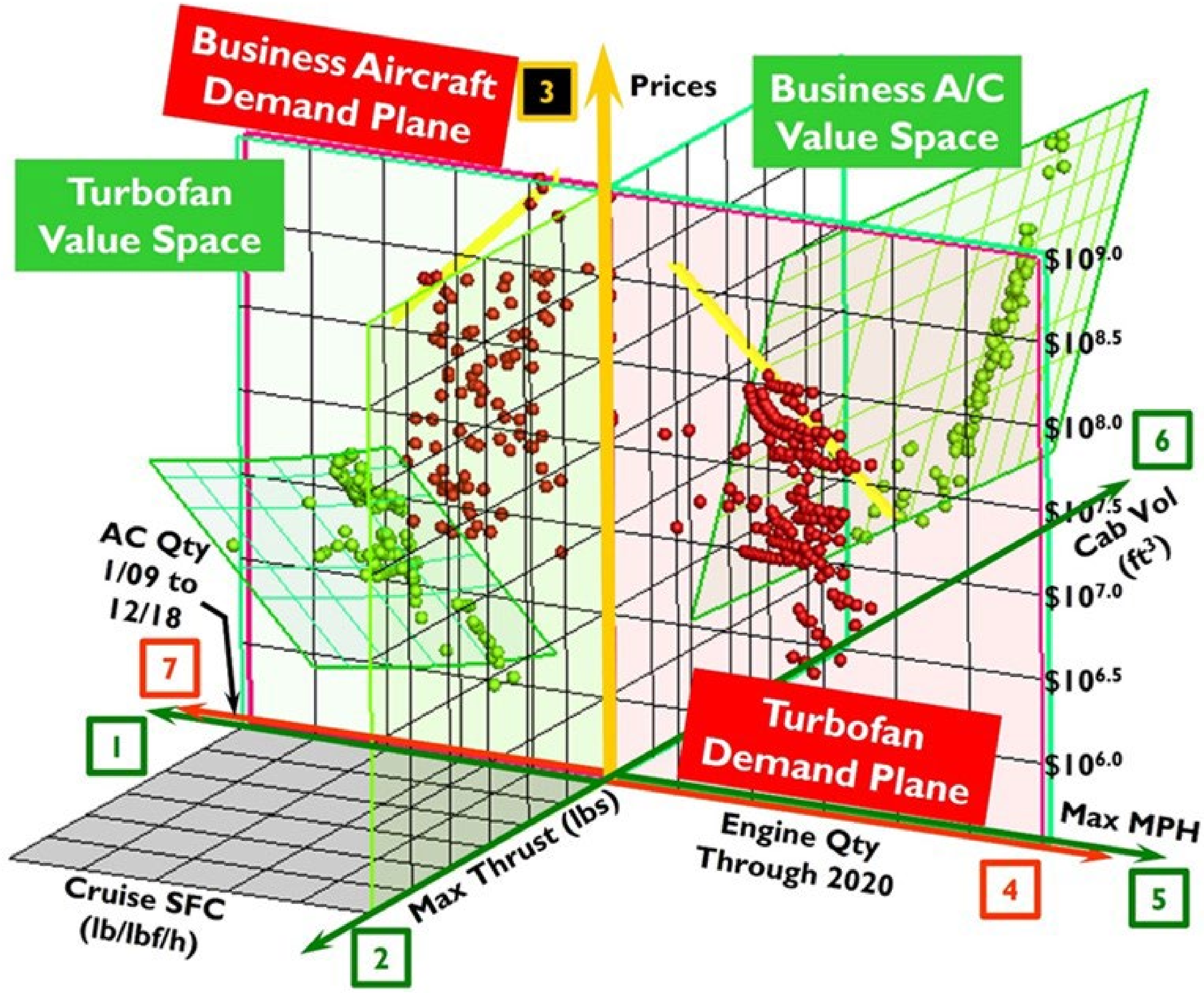

Figure 7 – Since the 4D business jet market and the 4D turbofan engine market share the price axis, when it comes to dimensions, 4+4=7. In this view, we have the turbofans in front, with Cruise SFC (Dimension 1) and Max Thrust (Dimension 2) for Valued Attributes driving Price (Dimension 3), while engine Prices limit their Quantity Sold (Dimension 4). At the same time, in the back portion of the diagram, Max Miles Per Hour (Dimension 5) and Cabin Volume (Dimension 6) push business Aircraft Prices (Dimension 3, as with the engines), with their Quantity Sold (Dimension 7) limited by prices and market saturation

4. How can we get to 13D?

Since we've managed to wrangle a 7D system that we could never see before, we might wonder what other techniques we might employ to expand our view further. Some seemingly simple observations can help lend insight into this problem we've set before ourselves. Let us entertain the swinging panel display we see in Figure 8. Such devices have been around for decades

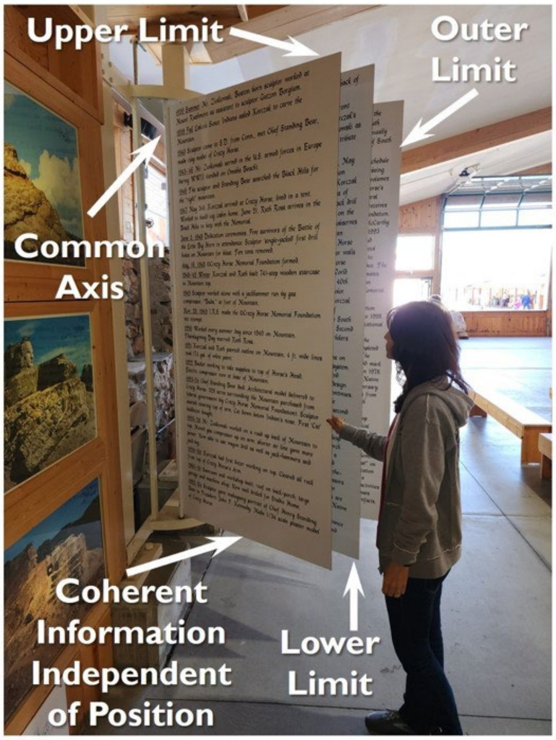

Figure 8 – Posters on a poster rack not only have upper, lower, and outer limits, but they all have a common axis, and the information on each card remains coherent regardless of position.

As Figure 8 displays, each card limits itself to its upper, lower, and outer boundaries. Crucially, in addition to those properties, each card works off the same vertical axis, and all of them retain all their data no matter what angle they take concerning the other cards. Given these observations, let's examine Figure 9, a simple 4D table of three general aviation aircraft models.

at least, and while they may appear simple, they have some unique ways of storing information.

Model	Seats	Max MPH	$M (2005)	Quan-tity
SR22	4	212	$0.29	1705
Baron 58	6	232	$1.00	330
Caravan I	8	213	$1.50	504

Figure 9 – Seats and Max MPH contribute to the Price of these General Aviation aircraft models and restrict their quantities sold

Once we have the information in Figure 9, we have enough data to craft a standard 4D model, as shown in Figure 10. While Figure 10 looks familiar and useful enough, we recall what we discovered in Figure 8. Specifically, we found that the data on a poster held its coherence regardless of its position on the central vertical axis. Knowing that, we can rotate the Demand Plane 15˚ clockwise in Figure 11 without losing information. Armed with that observation, we continue to rotate the Demand Plane to 30˚, 60˚, and 75˚, as depicted by Figures 12, 13, and 14, respectively. Finally, in Figure 15, we rotated the Demand 90˚, which lies flat against its respective Value Space. In the process, we've compressed the space needed to display a 4D system from 180˚ of arc to 90˚.

Since we successfully swung the Demand Plane onto Value Space, reducing the degrees of arc needed to portray a market, we might wonder if we can compress our data storage further.

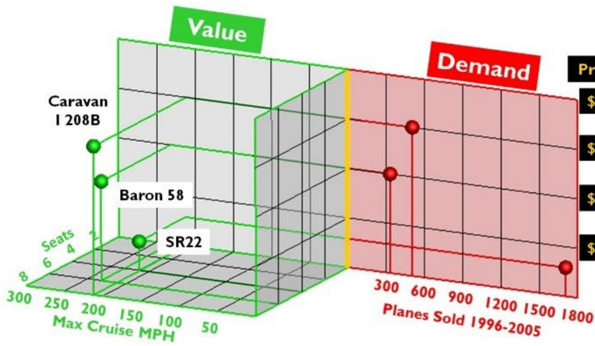

Figure 10 – A standard 4D model uses planes which are orthogonal to one another

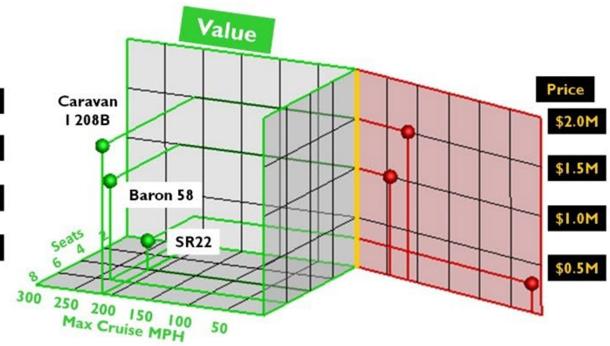

Figure 11 – The data in that model is not lost as we rotate the Demand Plane 15°

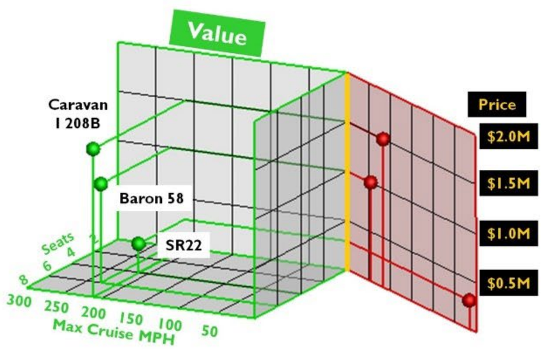

Figure 12 – The data stays coherent as we rotate the Demand Plane 30°

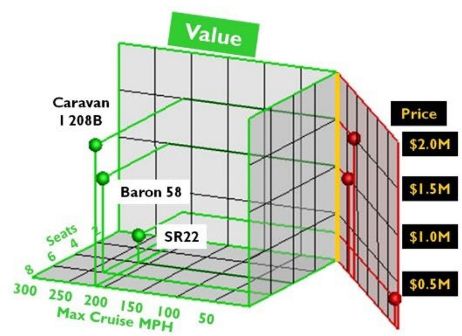

Figure 13 – No information loss occurs as we rotate the Demand Plane 60°

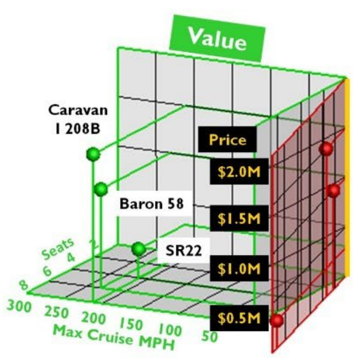

Figure 14 – We keep our information with the Demand Plane rotated 75°

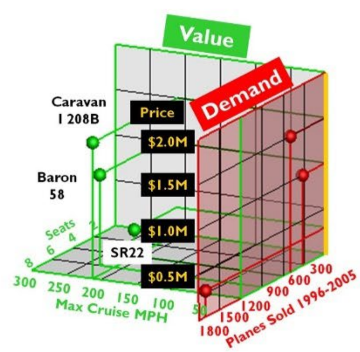

Figure 15 –The Demand Plane lies flat against Value Space when rotated 90°

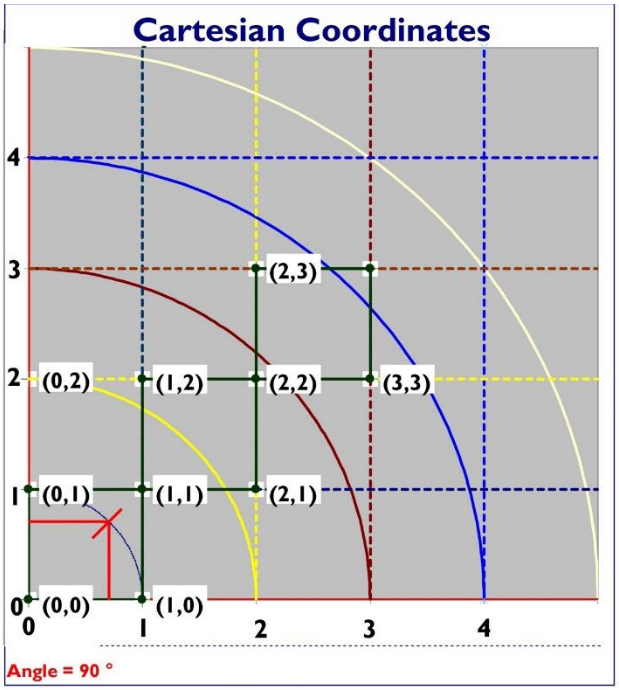

Figure 16 – Standard ordered pairs in standard orthogonal coordinates

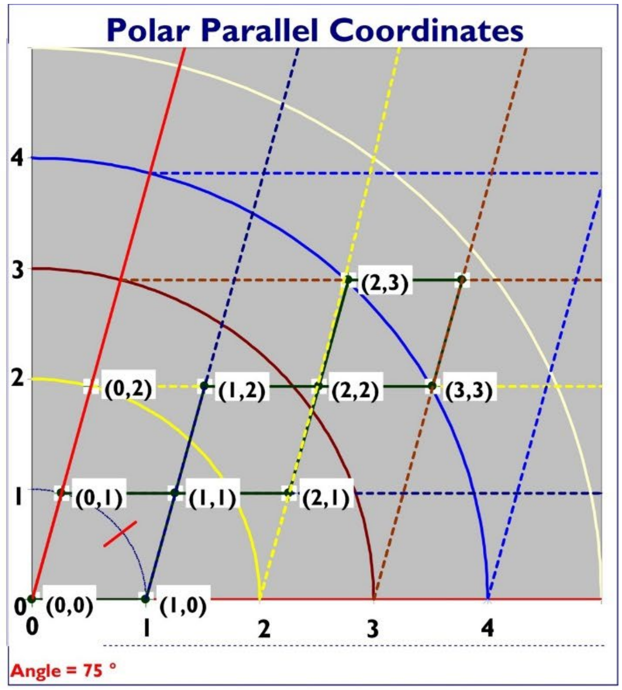

Figure 17 – Ordered pair data is not lost as we use parallelograms, condensing the view

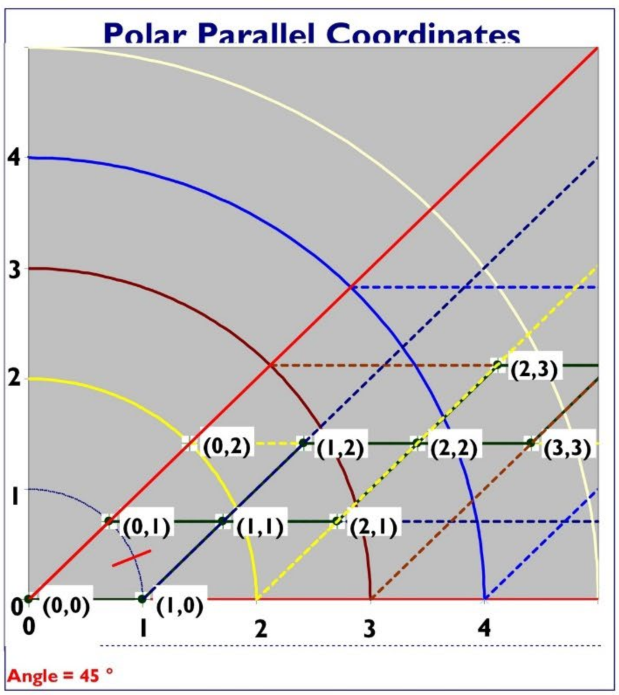

Figure 18 – The information remains intact with further data compression

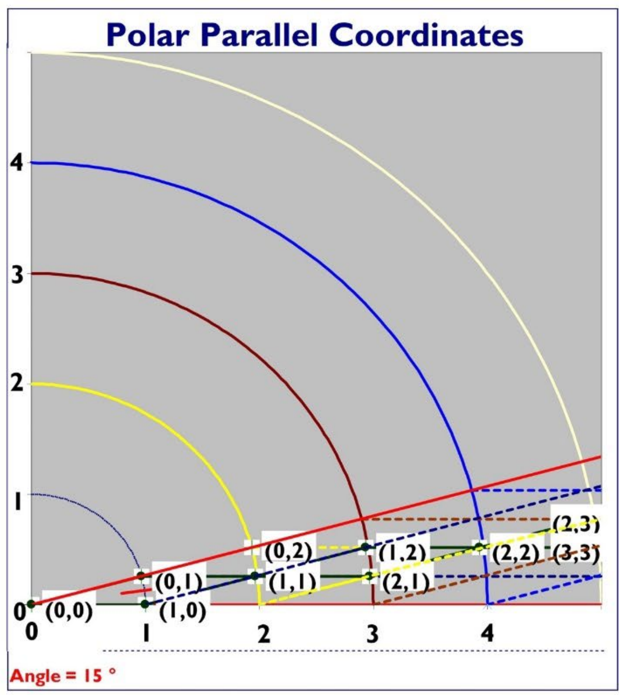

Figure 19 – The information is clearly infinitely compressible

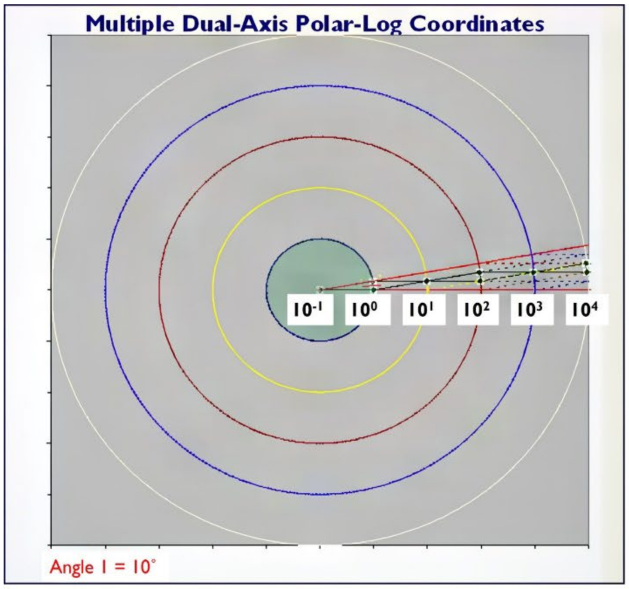

Figure 20 – The data we put into a 90˚ environment can be placed into a 360˚ view

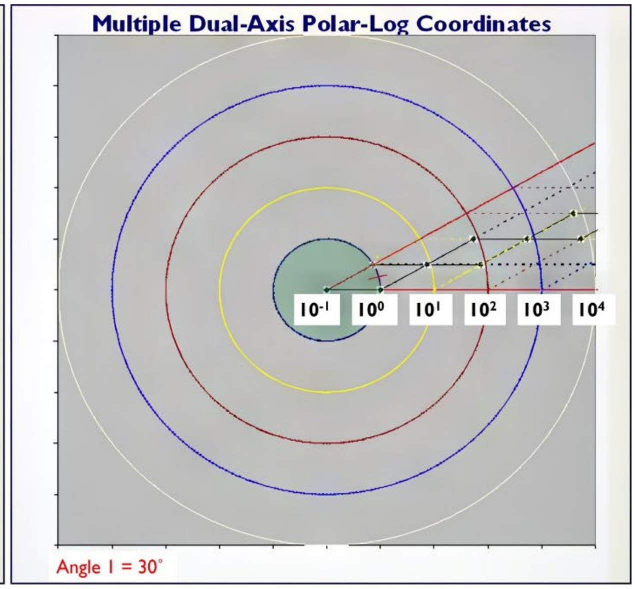

Figure 21 – As before, we can show any market with the appropriate angle

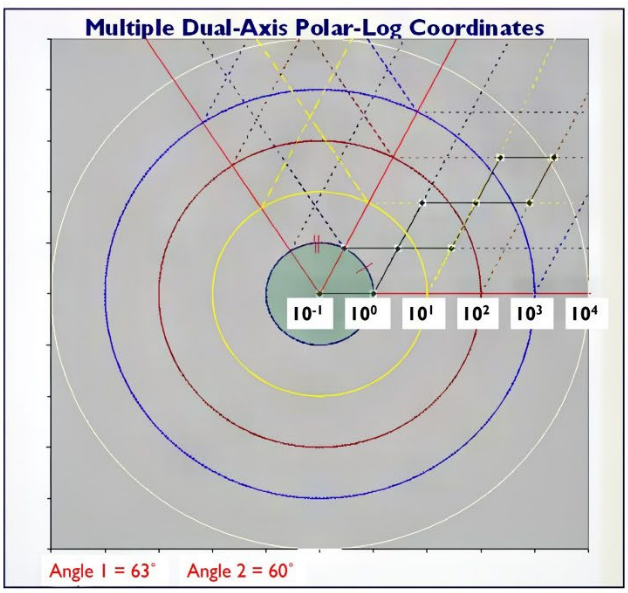

Figure 22 – We can add another market if we need to expand our analysis

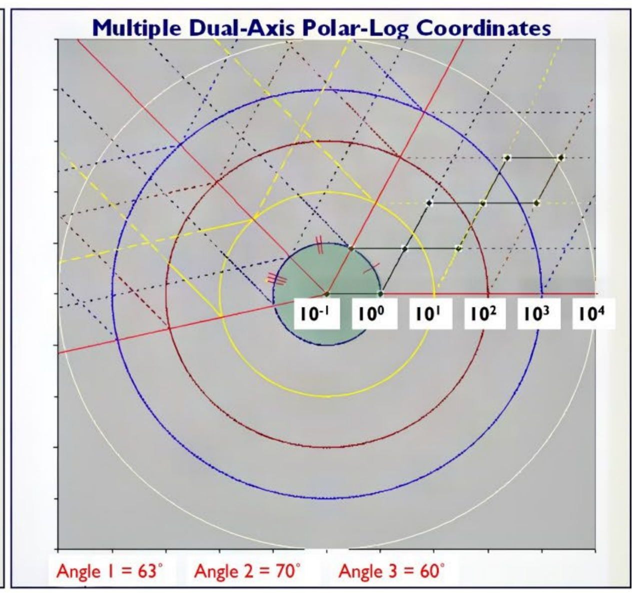

Figure 23 – We can keep adding as many markets as we would like to see

With Figure 16, we begin to study what we can do based on the six figures previous to it. In this Figure, we plot some whole number ordered pairs, which we label as indicated. Every pairing matches our long-standing sense of how we account for position in this realm.

But, in Figure 17, we adjust the angle between the traditional X and Y axes from 90˚ to 75˚. Importantly, we can still make sense of the location of all the ordered pairs with which we began as the angles between them form parallelograms, with their "vertical" distance to the origin remaining constant and their "horizontal" component relative to their neighbors unchanged as well. These are Polar Parallel Coordinates, using pantographs like Thomas Jefferson did with his Portable Polygraph, built by John Hawkins.[7] Figures 18 and 19 confirm we continue to track those numbers as the subtended axes collapse.

While Figures 16-19 examine the dimensional collapse across what amounts to one quadrant, or 90˚, of arc, Figures 20-23 study the effects of expanding the analysis to 360˚ and adding other markets. Figures 20 and 21 remind us of what we saw in the four figures previous to them, excepting only that they now appear across an entire 360˚ circle. Crucially, in Figure 22, we find we can easily add another market of a certain angle, while in Figure 23, yet one more market appears, and we have a full accounting of it. So, if we wanted to portray more markets, how would we go about it? Clearly, we just demonstrated that we could add as many markets as we care to. How might we apply these concepts to World GDP?

First, let's entertain how World GDP is broken down into three primary categories, according to the United States Central Intelligence Agency (CIA), as they envisioned it in 2014 in Figure 24.

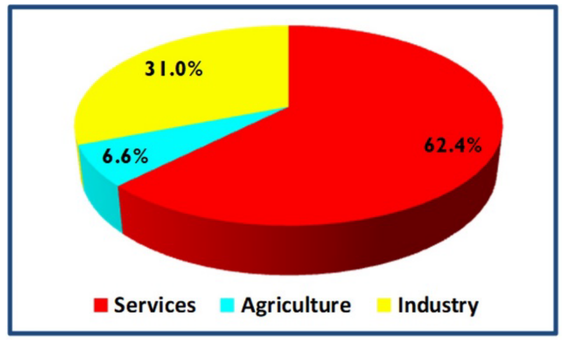

Figure 24 - The United States Central Intelligence Agency estimated 2014 World GDP to be $78.28 trillion, broken into three categories. [8]

While Figure 24 is highly informative, given our recent work, we wonder if we could add some additional insight into what the CIA has offered us. We might start by depicting GDP as a cylinder, as in Figure 25.

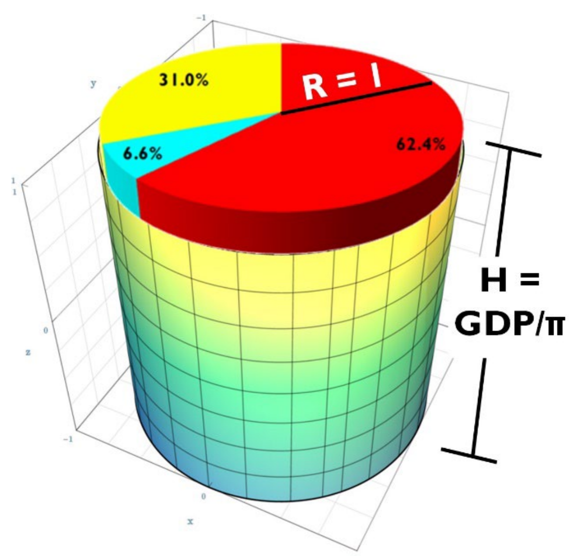

Figure 25 – We can envision GDP forming a tall cylinder, of height GDP/π [9]

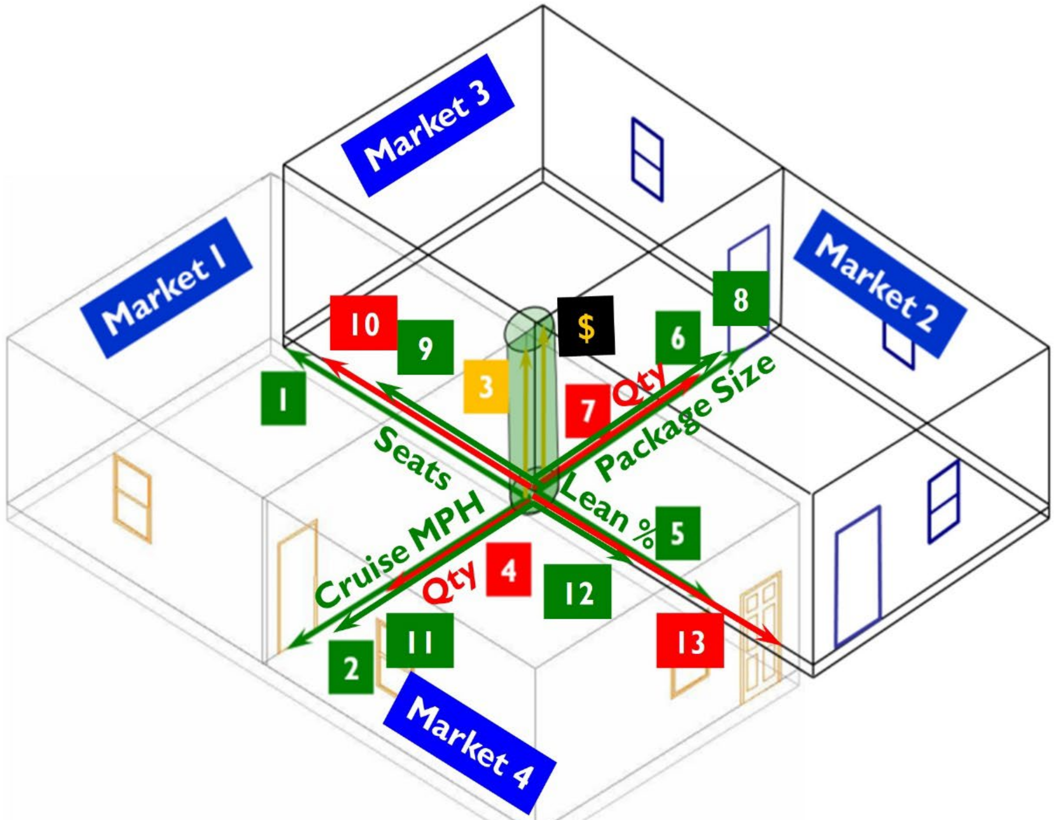

Figure 26 – If we collapse each Value Space to 90° of arc, and swing its paired Demand Plane flat against it, we can produce this system in which we portray four markets simultaneously.

Markets	Value Dimensions	Quantity Dimensions	Currency Dimension	Total Dimensions
1	2	1	1	4
2	4	2	1	7
3	6	3	1	10
4	8	4	1	13
n	2n	n	1	3n + 1

Figure 27 – Every market has two primary Value Dimensions and one Quantity Dimension. All markets share the Currency (or Price) Dimension. Thus, to plot n markets, we need 3n+1 dimensions.

Now, Figure 10-15 taught us that we could reduce four markets simultaneously, such that each would require 90˚ of arc. We also learned in Figure 25 that we could portray GDP as a tall cylinder, which, if it had a radius of 1, would have a height of GDP/π. Now, if we combine both of these insights and take the log of the GDP cylinder, we get the view we see in Figure 26. Each of the four markets has its Value axes at 90˚ to each other and has its Demand Plane lying flat against the Value Space. Here, Market 1 is an extension of the data used in Figures 10-15, where we studied General Aviation aircraft. Market 2 considers ground beef, where package size and leanness are a pair of primary Value considerations, and where it has its Demand Plane lying flat against the Value Space. Markets 3 and 4 (which could be anything) behave the same way. When we study these markets collectively, we notice a pattern forming, which we display in Figure 27.

It recognizes that the first market has a pair of Value dimensions, a single Quantity dimension, and one price dimension for four dimensions. The second market also has an identical number of Value and Demand dimensions but shares the Price axis with the first market. That pattern repeats for the third and fourth markets, as every nth market has two Value dimensions and one Quantity dimension but shares the price axis with all other markets. Thus, Figure 27 observes that to plot any number of n markets, we need 3n+1 dimensions.

Figure 28 shows how to plot a multidimensional picture, showing the single market for commercial aircraft in 2014. There, the green central cylinder represents the world GDP, using the logs of the conventions described in Figures 24 and 25, with a radius of 1 and a height of $10^{13.4}$. Note that the circular rings running parallel to the base go outward in multiples of ten to a maximum of one trillion (10^{12}). Splitting the data up according to the GDP taken by each market begins with the "Zero Angle" plane, shown with a red outline, which separates manufacturing (the pie section from red to orange) from agriculture (that slice going from red to blue). The balance of the GDP goes to services, marked by the largest section that extends from the orange divider to the blue one.

By convention, each market has three planes that describe it. All of them share a common upper border, which is the most expensive item in that market in that year, while the lower border is the least costly good or service offered for sale in that market. In the case of Figure 28, the upper limit was $414M, while the lower limit was $129K. The lateral extent of each plane depicts the maximum extent of the sales (as quantities, here, 5063 for one year) or features offered for sale (with the maximum number of seats at 525 and Miles Per Hour at 617). With the Demand Plane hard against one of the Value Space Planes, the angle between the Value Planes offers that market's portion of the World GDP. In the condition at hand, this market accounts for a little over 1˚ of arc or roughly 0.31% of the world's output.

5. What's a 5-Market 16D System?

What we can imagine now, given the techniques we've adapted to our purposes, is that we can plot any number of markets at the same time. In Figure 29, employing the methodologies we just discovered, we rotate the Demand Planes onto their appropriately condensed Value Spaces for five markets and their associated 16 mathematical dimensions. This consists of two Valued Feature axes for each market, one Quantity axis for each market, and a single currency axis common to all markets. In addition to the Currency Dimension (Dimension 1) used for all markets, we include those from Figure 28 that we used for Aircraft (Dimensions 2, 3, and 4). Rapid shipping services employ Dimensions 5, 6, and 7, while we describe the market for ground beef in the United States using Dimensions 8, 9, and 10. For personal transportation, we entertain Dimensions 11, 12, and 13 for cars with Internal Combustion Engines (ICE) and Dimensions 14, 15, and 16 for electric cars.

Observe that the Internal Combustion Engines (ICE) car market forms the largest market in this study, with 2.35% of world GDP, over 347 times that for electric cars.

As we can see, there is no limit to the number of markets we can characterize in this fashion.

Importantly, suppose we reflect on markets dating back to the beginnings of humanity and compare them to what we see in Figure 29. In that case, we can imagine some dramatic changes in what people buy and sell now versus what they did long ago.

To make our reflection more complete, we'll focus on a market that has been around for as long as we have, and take it from a long time ago to the present, stopping at various points along the way. In so doing, we'll see how that market evolved as we did.

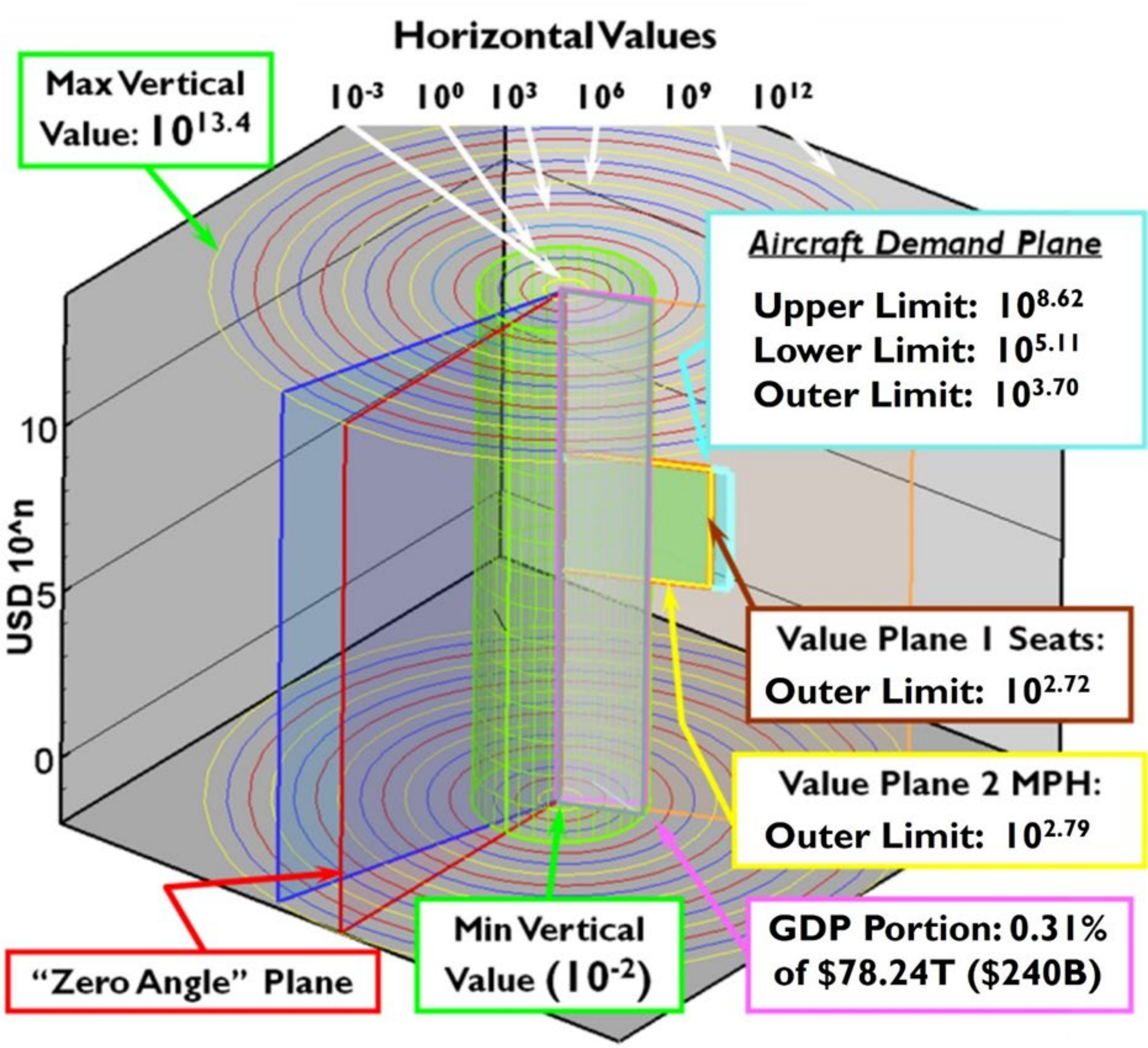

Figure 28 With the "Zero Angle" red plane as a starting point, we go counterclockwise to the orange, blue, and back to the red planes, thus marking industry, services, and agriculture in that order. Note that the concentric horizontal values begin at 10^{-4} and go in powers of 10 to 10^{12}, which is our arbitrary outer limit. Note the inner green circle with a radius of 1 (10^0), which is our GDP pie column. The pink plane that reaches from the center horizontally out to 1, and up from 10^{-2} (our bottom) to $10^{13.4}$ forms a wedge with the orange plane. This wedge is the portion of GDP (0.31%) dedicated to commercial aircraft sales. We mark this market's demand in the light blue plane, with the bottom of it representing the lowest priced vehicle in the market ($129,000 or $10^{5.11}$), while the upper limit is for the most expensive vehicle ($414 million, or $10^{8.62}$), while the lateral extent of this plane describes yearly sales (5063, or $10^{3.7}$). We keep Value Planes with the same upper and lower limits, while the lateral extents of Value Planes 1 and 2 indicate the maximum number of seats (525 or $10^{2.72}$) and miles per hour (617 or $10^{2.79}$), respectively. The angle between the aircraft value planes is 1.11° or 0.31% of the global GDP. This market is a little more than 1/300th of GDP.

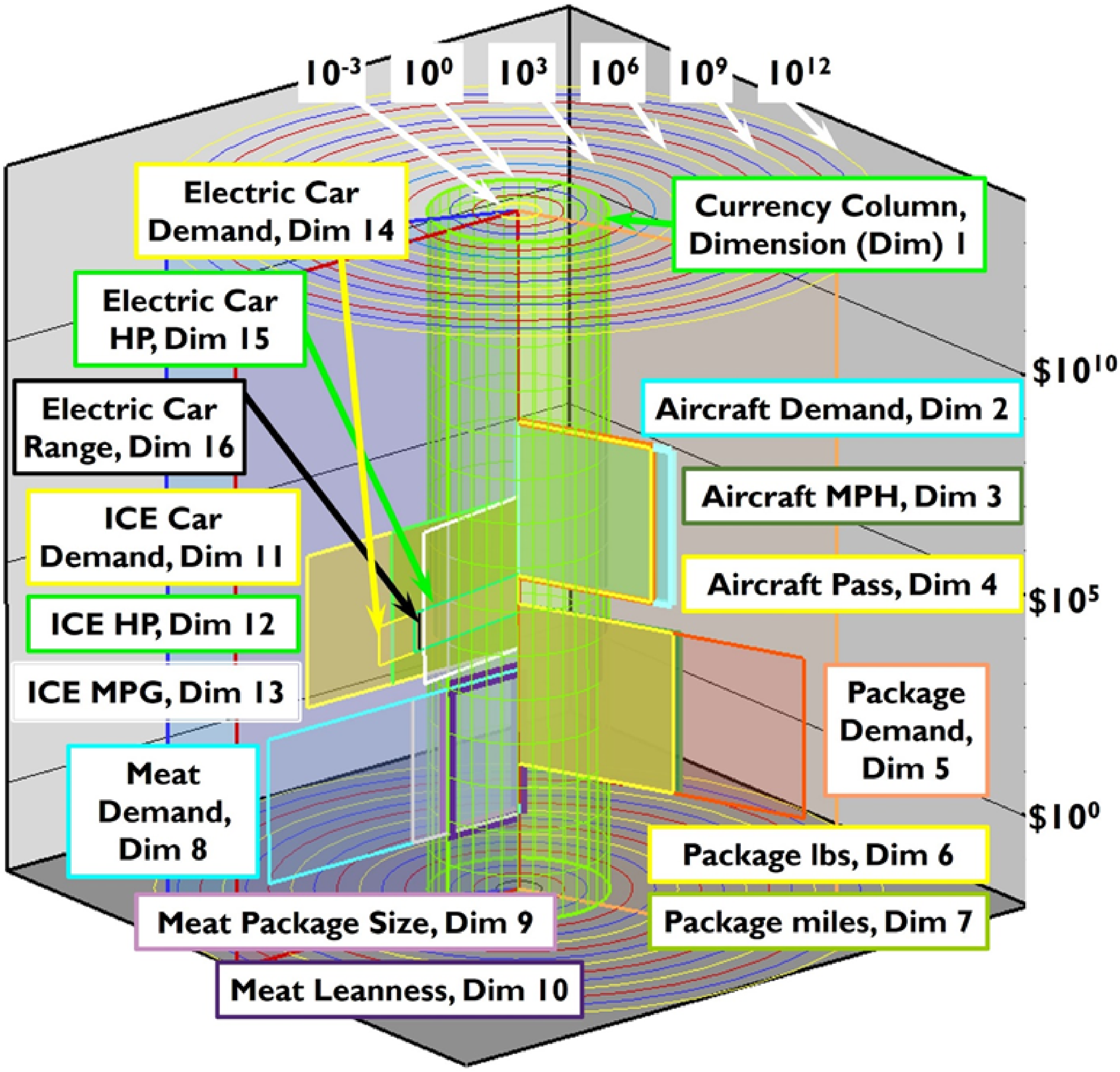

Figure 29 - Using some of the recent techniques that we just learned, we swing the Demand Planes onto compressed Value Spaces for five markets and employ 16 mathematical dimensions. This consists of two Valued Feature axes for each market, one Quantity axis for each market, along with a single currency axis common to all markets. In theory, there is no limit to the number of markets that we characterize in this fashion. Note that the market for cars with Internal Combustion Engines (ICE) forms the largest market in this study, with 2.35% of world GDP, over 347 times that for electric cars.

6. A Partial History of Surveillance

Surveillance predates mankind. How can I make such a statement? It's not as if we have records of what happened hundreds of thousands or millions of years ago. What do we have to make that assertion?

A few months ago, I was at the end of a trailhead after a long run. Standing in the parking lot, bent over and struggling to catch my breath, an ant caught my eye.

6.1 Ground Level Surveillance

Now ants had famously been interesting to Richard Feynman, the Nobel Prize-winning physicist.[10] He used to see how long it would take to find some sugar he put out for them. So, I began to study this ant. I thought, "If it is worth Dr. Feynman's time, why can't I spend a minute doing this?"

By jagged fits and starts, this tiny ant, something less than a quarter inch in length, began turning in a counterclockwise motion, slowly bending to its left in what eventually appeared to be a circle, except that after turning a complete 360˚, the endpoint was outside where it started. With each pause, it appeared on a slightly higher rock than before. It made another counterclockwise ring and then one more, forming a broadening spiral. Then it hit me: That ant was doing reconnaissance.

I rushed home and put "ant reconnaissance" into a Google search bar. A short search revealed that ants who nest in flat rock crevices perform surveillance while looking for new nests, seeking to avoid competing colonies and weighing out features such as floor space, headroom, and cleanliness of their sites.[11] More research revealed that this genus, Temnothorax, has been on Earth for 140-168 million years, far predating humanity.[12]

Thus, with humans being smarter than ants, we can conclude that people have been doing surveillance since their emergence. While we don't have any records of these activities before the historical record began, we do have examples of how we performed surveillance in the past.[12]

6.2 Fixed Elevated Surveillance

The ant upon which I had fixated used at least two surveillance methods I could observe. The widening circles gave it a broader area of coverage. And, by pausing on elevated rocks millimeters higher, the ant could increase its distance to its horizon. Both techniques offered increased information about the surrounding area.

Humans evolved more ways to gain data about their adversaries.

The watch tower Vartovka (see Figure 30), erected to warn the citizens of nearby Krupina, Slovakia, of invading armies, was built in the late 1500s. Its elevation offered a longer distance to its field of view and, when joined by several other like structures, gave the town advanced early warning of armies invading from multiple directions.

While it and others like it constructed atop the surrounding hills served the town well, it placed a heavy financial burden on the local townspeople. Such structures are still being built for prisons and spotting fires, but armies needed more flexibility. What if the enemy is on the move or far away from the city needing protection? Heads of state required other methods to gain insight into their battlefields.

Figure 30 – The Vartovka watchtower, (with a modern staircase and reconstructed porch added to it), was paired with similar sentry posts to offer advance warning of approaching armies.

6.3 Mobile Aerial Surveillance

Brothers Joseph and Etienne Montgolfier in Annonay, France, created the first lighter-than-air balloon in 1783. After carrying animals on their first flight, they quickly transitioned to carrying people in the same year, first using tethers and then graduating to free flights.[13] The French military was quick to appreciate its surveillance potential.

The French were the first to use balloons by military forces in 1794, and they were used irregularly for reconnaissance in the French Revolutionary Wars.[14] They appreciated the portability. Now, anywhere a battle arose, they could enjoy views that previously would have taken an intensive tower construction for a fraction of the cost.

Nearly 70 years later, the United States was fighting the Civil War. As in all conflicts, each side wanted to know what the other was doing, and both decided that using balloons could aid in doing reconnaissance. We can see how the Union went about the business of filling one of these balloons in Figure 31.[15] [16]

Perhaps their most famous use in that war was when Thaddeus S.C. Lowe went on a tethered flight in one of his balloons on July 24, 1861, three days after the Battle of Bull Run, and determined the Confederate troops were not on their way to Washington DC. This was useful information, and tethered balloons became a part of modern reconnaissance during the Civil War. Their large size and relatively fixed positions became problematic, though, as they afforded large, slow-moving targets.

As time passed, motorized balloons became important in World War I, either non-rigid (blimps) or rigid (Zeppelins, for example). However, given their large size and relative lack of mobility, they were often easy targets for enemy fire and were retired mainly in favor of smaller, more nimble platforms.

Those less bulky and faster machines were, of course, airplanes.

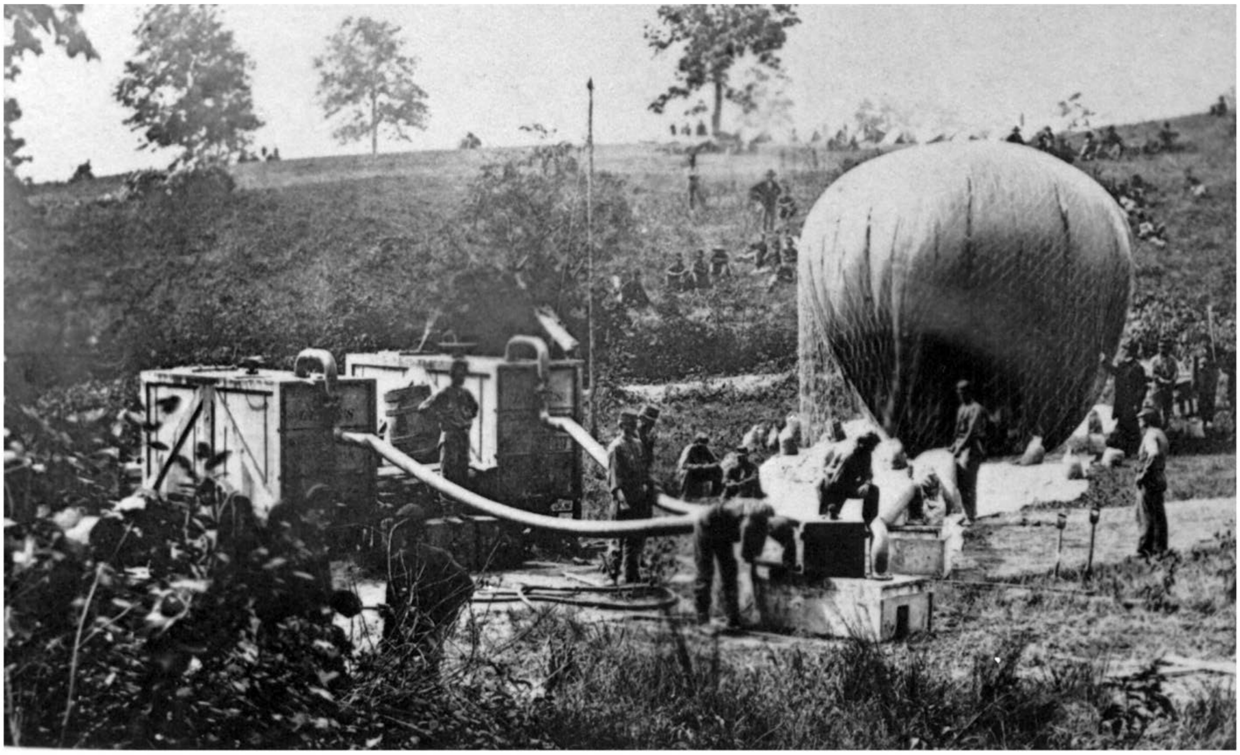

Figure 31 – The Union balloon *Intrepid* had a capacity of 32,000 cubic feet of lifting gas (Hydrogen). Hydrogen-generating wagons supplied it. Thaddeus S. C. Lowe, one of the most famous balloonists at the start of the Civil War, built these wagons, which reacted sulfuric acid with iron filings to produce hydrogen gas to fill the *Intrepid*.

6.4 Faster, Higher Aerial Surveillance

In World War I, slightly more than a decade removed from the Wright Brothers' first flight, not entirely satisfied with the information they could get from the blimps, whose low ceilings, slow speeds, and large sizes made them excellent targets, the Allied Powers worked hard to get planes that flew higher to retrieve the intelligence they each needed.

One workhorse of the conflict for the Allies was the Caudron G.3. Over 2800 copies were built in World War 1, the vast majority coming from France. While it went only slightly faster than the best lighter-than-air aircraft of the day (the G. 3's top speed was 66 miles per hour, and some German Zeppelins could hit 54 to 60 miles per hour), its ceiling was quite a bit higher (the G.3 could reach 14,100 feet altitude, most German Zeppelins but early in the war had ceilings less than 10,000 feet).[17] [18]

While the Caudron G.3 technological improvement offered the Allies an edge early in the conflict, the plane's limitations became evident as the war dragged on, as shown in Figure 32. At right, getting too close to the action nearly cost the pilot his life. Going higher and faster seemed like a better option.

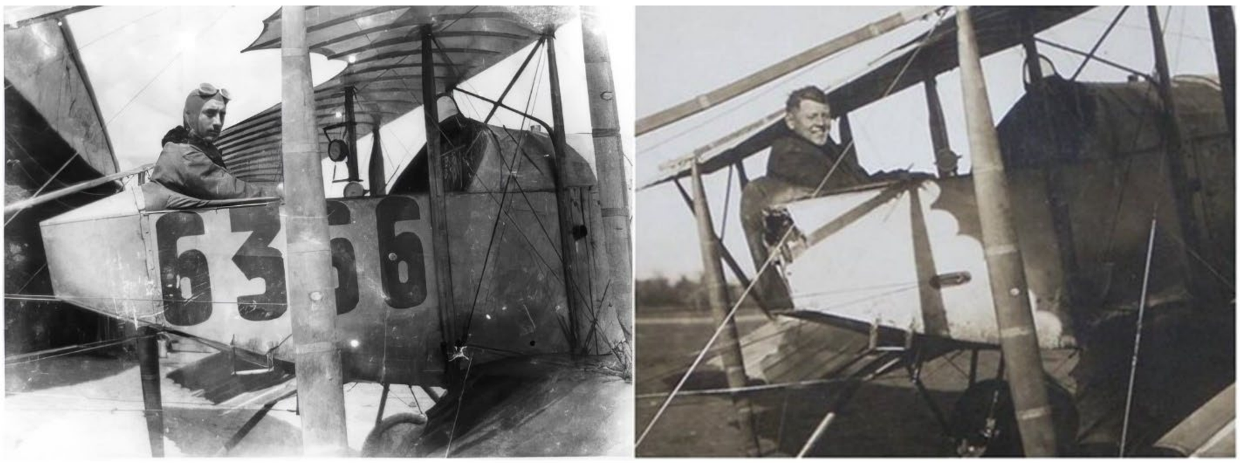

Figure 32 – On the left is a pilot of the Allied Powers in a Caudron G.3, used for training and reconnaissance in World War 1. Note the metallic aft fuselage to the left of its serial number 6366. At right, the same model after a mission piloted by Everett Howarth (my grandfather). Note the torn-off aft fuselage, hit by friendly fire. Reconnaissance missions are uniquely dangerous, and there has been an ongoing movement to perform surveillance using better and safer methods and platforms since surveillance began.

6.5 Ever Faster & Higher Surveillance

The hard-won lessons about reconnaissance plane losses from World Wars I and II were not lost in the intelligence community. With anti-aircraft batteries improving for the Soviet Bloc, as Cold War tensions brewed, it became imperative to be able to outfly ground-launched attacks on spy planes.

Lockheed (before it was Lockheed Martin) came up with a pair of solutions, the U-2 and SR-71 (Figure 33).[19][20]

First came the U-2, a single-engine spy plane that could fly higher at altitudes exceeding 80,000 feet, as it cruised at a rather pedestrian 470 miles per hour. As it entered operational service, that service ceiling exceeded the ability of any opponent's missiles to reach it. But then, after years of enjoying no opposition to its flights, a U-2 was shot down over the Soviet Union.

That incident called for another innovation from Lockheed, the SR-71. Flying only slightly higher than the U-2 at 85,000, its primary advantage was its top speed, which, at 2200 miles per hour, was nearly five times faster than the U-2, exceeding the ability of any surface-to-air missile to reach it. It also introduced the world to the first revealed attempts at reducing the radar cross sections of the plane as one of the first implementations of stealth. No SR-71 was ever lost to hostile actions. However, it was not immune to budget issues, and in 1989, it was retired due to the high cost of its maintenance.

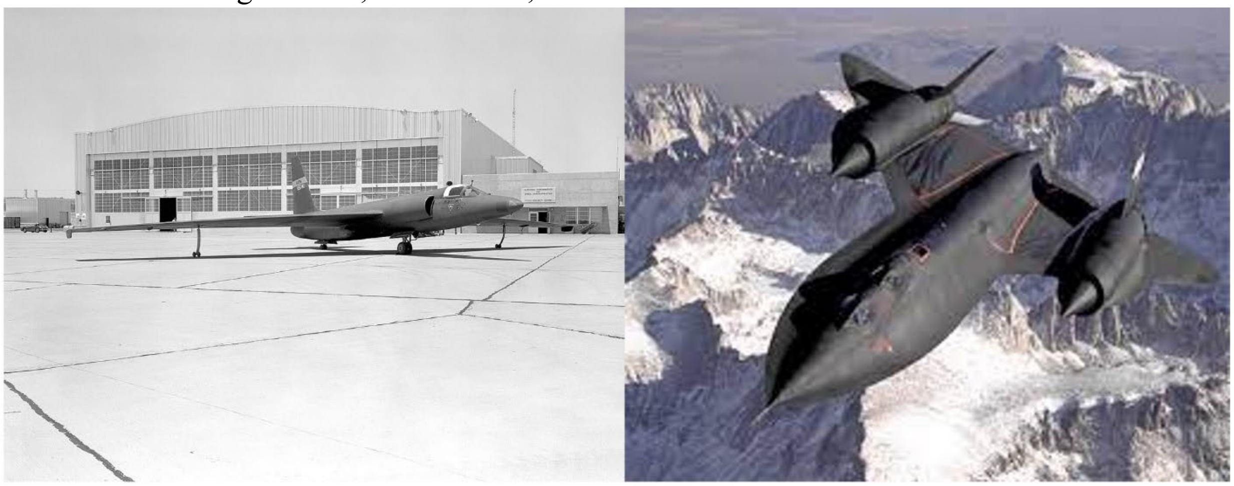

Figure 33 – The U-2 spy plane on the left flew higher than anything else in the sky when it was first conceived and flown. It could fly with impunity over Eastern Bloc territory for years. Then, as often occurs in this arena, opponents to US interests caught up, as the Russians designed and built a missile that took down a U-2 over Soviet Territory. That incident forced the development of the SR-71 (right), which flies at 85K+ feet and travels over 2200 MPH. While it was never shot down, its high price forced the USAF to discontinue its use.

6.6 Unmanned Aerial Surveillance

Our Figure 2 revealed that a large portion of modern aerial surveillance has migrated away from planes with pilots in the cockpit to Unmanned Air Vehicles (UAVs) and Satellites. As we found out, these disparate product forms perform the same missions and end up having the same Minimum Demand and Outer Demand Frontiers. We might guess that customers for both types of platforms respond to the same types of features offered by both groups, and we would be right, as we see in Figure 34.

The beneficial and perhaps unexpected outcome of combining UAVs with satellites is that the features that predict their Values and the markets' response to them boil down to one single equation.

That equation is

$$\$M = 0.0290 * PL\ lbs^{0.766} * Max\ MPH^{0.301} * Alt\ Miles^{0.169} * Qty^{-0.283} \quad (1)$$

Where:

$M = Estimated Price per unit in 2021$M
PL lbs = Payload pounds
Max MPH = Maximum Speed in Miles Per Hour
Alt Miles = Maximum Altitude in Miles
Qty = Total Quantity Sold through 2021

Equation 1 has an Adjusted R^2 of 96.1%, a Mean Absolute Percentage Error (MAPE) of 71.3%, an overall p-value of 8.83E-39, and p-values of 3.16E-15, 1.53%, 0.42% and

0.13% for PL lbs, Max MPH, Alt Miles, and Quantity sold, respectively.

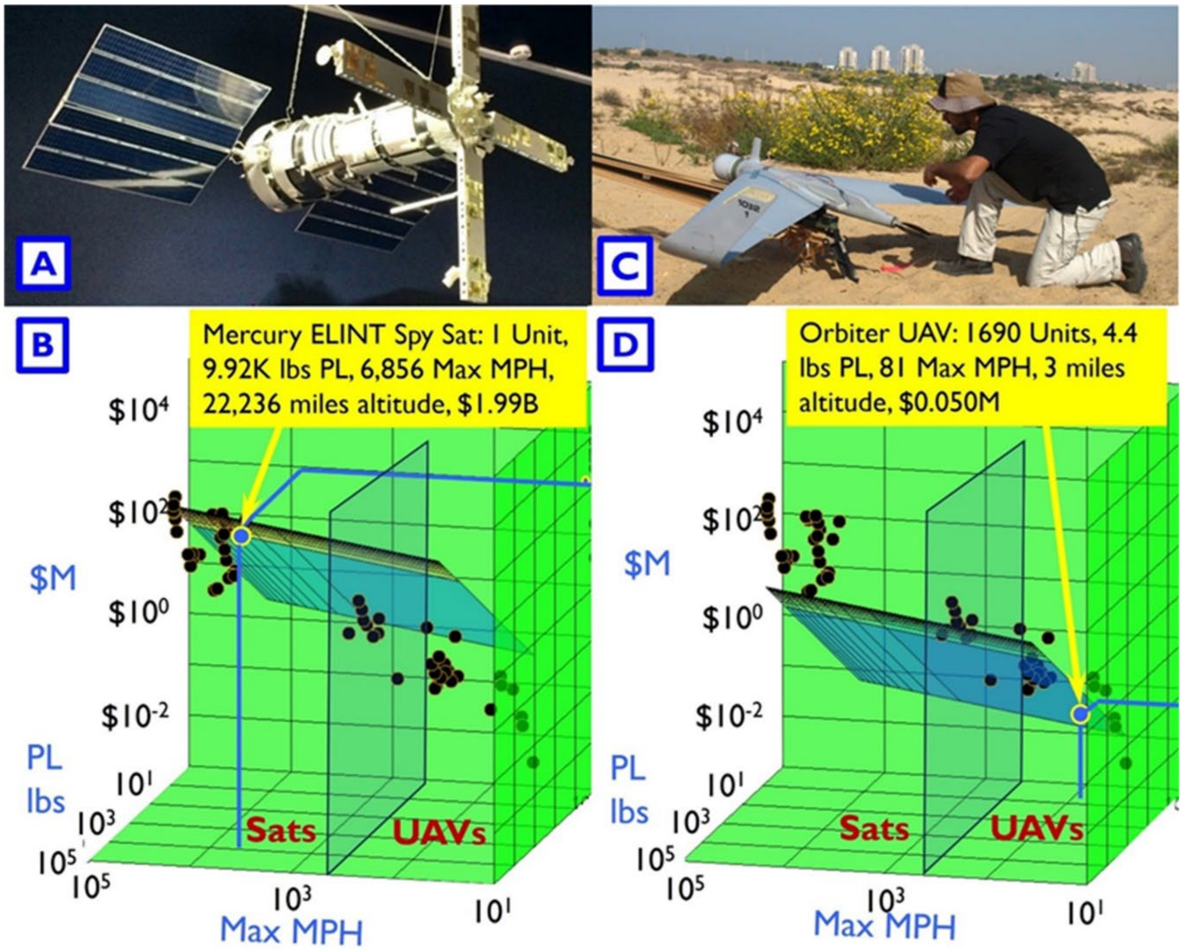

Figure 34 – The Russians run ELectronic INTelligence (ELINT) satellites over the US (A). Western forces must get the same insight to be as well-informed. Using the same equation, we can predict the Value (sustainable price) of Western Bloc satellites and UAVs. In (B), with 30 Sats on the left and 30 UAVs on the right, we predict the Value of the US Mercury ELINT satellite using an equation considering 1) Payload, 2) Max MPH, 3) Altitude, and 4) Quantity sold. We highlight the Israeli Orbiter UAV (C) estimate using the same equation in (D). With an adjusted R2 of 96.1%, its p-value is 8.83E-39.

When we combine the analysis of the Value of these platforms with their Demand and recurring costs, we can obtain the view we see in Figure 35. Here, we have posited making a new Low Earth Orbiting (LEO) satellite, with an orbit 500 miles above the Earth. We're proposing a 4000-pound payload, and, given the orbit we've chosen, we'll be going about 17,000 miles per hour. If we set our targeted sales to 20, our ultimate average Price will be $290M per unit. Given our assumed Empty Weight, we'll find that our first unit, or T-1, cost will be relatively high. To gain all the sales we want for this new platform, we must seek to keep our learning curve for it at 91% or lower.

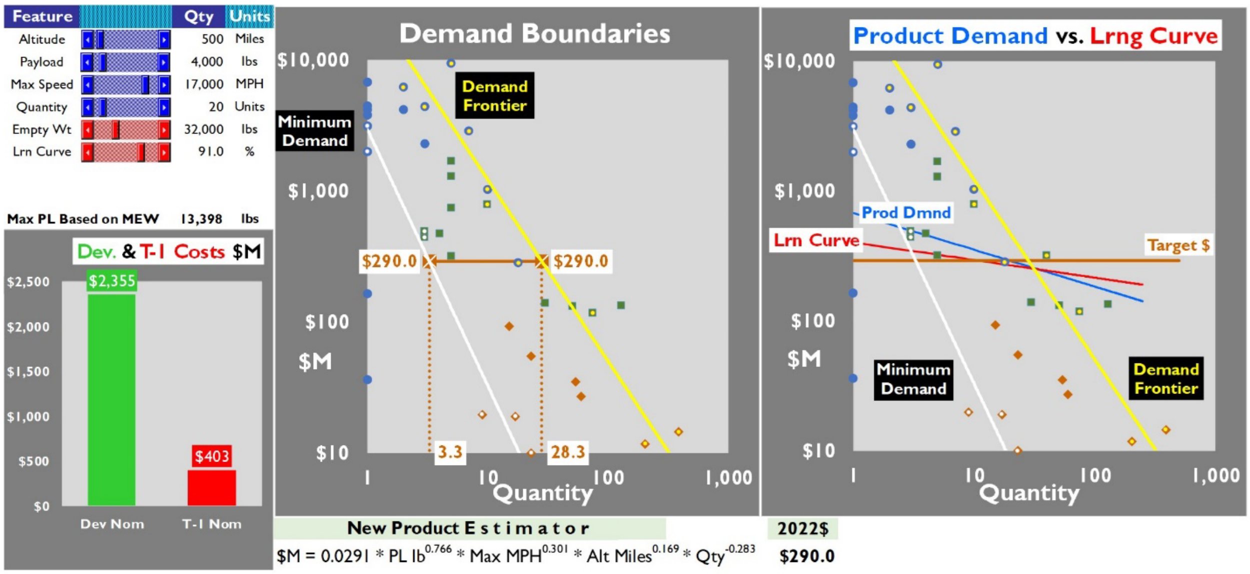

Figure 35 – You want to build an unmanned surveillance platform—what features will you offer? That combination of specifications will determine the product Value (as a sustainable price). Assuming that your new product is viable, that Price sets Minimum and Maximum Demand Limits. Once you know your price and quantity target, you'll need to calculate the T-1 cost which, in conjunction with your Learning Curve, either lets you hit your ultimate sales goal or fall short.

7. Summary and Conclusions

Some markets come and go. Others change over time. Modern plotting techniques let us portray any market in four dimensions, two in seven dimensions, and so on. Understanding how related markets work together is critical to ensuring they will survive. Plotting all markets in the world simultaneously using a system that amounts to a vertical rolodex with unique properties laid out in advance is possible.

Humans have spent time doing surveillance since they first walked on Earth. While the methods change, the objective has always been to provide more information about our surroundings and potential enemies than we had before. Even ants search for higher ground, and we can quantify what humans will pay for those vantage points. Speed is crucial in many realms, but never more so than in surveillance, where delays in getting information can kill you. Newer platforms may require us to take along specialized gear as payloads, and the more Payload we can carry, the more it is worth to us. On the other hand, as prices rise, we buy less, and when it comes to aerial surveillance, as we buy more, each succeeding unit is worth less to us. Knowing how these forces work with and against each other is crucial if we are to make new products successful.

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